GIS APPLICATION AND ENVIRONMENTAL FACTORS FOR MOSQUITO CONTROL IN EASTERN PROVINCE, SAUDI ARABIA

BY

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DEDICATION

I dedicate my thesis to my parents.

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LIST OF ABBREVIATIONS

ASTHO	:	Association of State and Territorial Health Official
DPMIAC	:	Defense Pest Management Information Analysis Center
ESRI	:	Environmental Systems Research Institute
GIS	:	Geographic Information System
GPS	:	Global Positioning System
KSA	:	Kingdom of Saudi Arabia
MBDs	:	Mosquito-Borne Diseases
MOH	:	Ministry of Health
PME	:	Presidency of Meteorology and Environment
PMH	:	Per Man Hour
RH	:	Relative Humidity
WHO	:	World Health Organization

ABSTRACT

Full Name : [Yasin Jemal Yasin]

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The influence of mosquitoes on human health and well-being is greater than any other insects throughout the world. This is due to the diseases they transmit and the severe nuisance they cause to humans. Diseases transmitted by mosquito vectors are among the major contributors to human morbidity and mortality in each parts of the world. Understanding the environmental/climatic factors (temperature, relative humidity and rainfall) that govern the distribution and abundance of mosquito is fundamental for mosquito control. Supplementation of this information using Geographic Information System (GIS) to map the location of larvae breeding habitat makes the mosquito control activities easier, more effective and efficient than the traditional methods of mosquito control.

This study aims to map mosquito larvae breeding sites using GIS application and determine the effect of environmental/climatic factors (temperature, relative humidity and rainfall) on mosquito distribution and abundance in Eastern Province, Saudi Arabia. The data pertaining to larval and adult mosquito abundance/distribution and climatic factors were collected during a year period, in 2014. Bivariate and multivariate analyses were performed

using IBM® SPSS® version_20.0 to determine the relationship between mosquito abundance and climatic factors (temperature, relative humidity and rainfall). The employment of GIS with Geographic Positioning System (GPS) facilitates the identification and mapping of larvae breeding sites in the study area.

Larval and adult mosquito were collected from eight sites including Abu Main, Umm As Sahik, Safwa, Al-Awjam, Dammam, Al-Qatif and its surrounding area, Buqayq and Al-Sarar. A total of 31041 mosquito larvae and 2036 adult mosquito were collected during a year period, in 2014. High number of larval and adult mosquito were collected at temperatures that ranged between 16.4 ^{o}C to 27.7 ^{o}C and between 15 ^{o}C to 27.7 ^{o}C respectively. The bivariate analysis showed strong negative correlation between mosquito abundance and temperature while strong positive correlation with relative humidity and moderate positive correlation with rainfall. Low mosquito abundance was observed at high temperatures whereas high and moderate mosquito abundance was observed at high humidity and during rainy months, respectively. The regression analysis indicated that the three climatic factors (temperature, RH and rainfall) accounted 64.3% (R^2 = 0.643) and 84.5% (R^2 = 0.845) of the variance in larval and adult mosquito abundance in Eastern Province, respectively. In addition to the effect of climatic factors, the presence of floating and terrestrial vegetation, waste debris, extensive irrigation activities and poor environmental sanitation also contribute for the wide distribution of mosquito in many habitats in the study area.

ملخص الرسالة

الاسم الكامل: ياسين جمال ياسين

عنوان الرسالة: تطبيق نظام المعلومات الجغرافية وتأثير العوامل البيئية لمكافحة البعوض في المنطقة الشرقية من المملكة العربية السعودية

التخصص: العلوم البيئية

تاريخ الدرجة العلمية: أكتوبر,2015.

يؤثر البعوض على صحة الإنسان ورفاهيته أكثر من أي حشره أخرى في جميع أنحاء العالم. وان هذا التأثير سببه الأمراض التي ينقلها والإزعاج الشديد. ان الأمراض المنقولة بواسطة البعوض الناقل تعتبر من أهم المساهمين الرئيسيين للإصابة بالأمراض والوفيات عالميا. أن فهم العوامل البيئية/المناخية (درجة الحرارة والرطوبة النسبية والأمطار) التي تتحكم في توزيع ووفرة البعوض أمر أساسي لمكافحة البعوض .أن من مكملات لهذه المعلومات أيضا استخدام نظام المعلومات الجغرافية (GIS) لتعيين مواقع تربية اليرقات بصورة دقيقه والذي يجعل أنشطة مكافحة البعوض أسهل وأكثر فعالية وكفاءة من الأساليب التقليدية لمكافحة البعوض.

تهدف هذه الدراسة إلى ايجاد خريطة لمواقع تربية يرقات البعوض باستخدام تطبيقات نظم المعلومات الجغرافية وتحديد مدى تأثير العوامل البيئية/المناخية (درجة الحرارة والرطوبة النسبية والأمطار) على توزيع البعوض ووفرته في المنطقة الشرقية بالمملكة العربية السعودية. حيث جمعت البيانات المتعلقة بوفرة اليرقات والبعوض البالغ وتوزيعها، بالإضافة للمعلومات عن العوامل المناخية خلال فترة سنة ولعام 2014.

أجريت التحليلات المتغيرين والمتغيرات باستخدام IBM ® SPSS ® version_20.0 لتحديد العلاقة بين وفرة البعوض والعوامل المناخية (درجة الحرارة والرطوبة النسبية والأمطار).

حيث تم توظيف نظم المعلومات الجغرافية مع نظام تحديد المواقع (GPS) لتسهل تحديد ورسم خرائط لمواقع تكاثر اليرقات والبعوض في منطقة الدراسة. لقد تم جمع يرقات البعوض والبالغ من ثمانية مواقع متعددة شملت أبو معان، أم الساهك، صفوة، الاوجام، القطيف، منطقة الدمام والمنطقة المحيطة بها شملت بقيق والصرار. لقد تم جمع ما مجموعة 31041 يرقه بعوض و2036 للبعوض البالغ خلال فترة سنة، ولعام 2014. حيث تم جمع عدد كبير من يرقات البعوض والبالغ في درجات الحرارة التي تراوحت بين 16.4 مئوية و27.7 وبين 15 و27.7 على التوالي.

أظهر تحليل المتغيرين علاقة سلبية قوية بين وفرة البعوض ودرجة الحرارة وعلاقة إيجابية قوية مع الرطوبة النسبية ومعتدلة مع هطول الأمطار. كما لوحظ انخفاض وفرة البعوض في درجات حرارة عالية بينما وفرتها عالية ومعتدلة عند ارتفاع نسبة الرطوبة وخلال شهور الأمطار، على التوالي. لقد أشار تحليل الانحدار إلى أن ثلاثة عوامل مناخية (حرارة ورطوبة نسبية وهطول الأمطار) وان التباين في وفرة البعوض اليرقات والبالغين في المنطقة الشرقية، بنسبة 64.3 في المائة (R2 = 0.643) و84.5 في المائة (R2 = 0.845) على التوالي. بالإضافة إلى تأثير العوامل المناخية، أن وجود النباتات البرية والعائمة، النفايات، وأنشطة الري واسعة النطاق وسوء حالة بيئية المرافق الصحية تؤثر على نطاق واسع على توزيع البعوض في منطقة الدراسة.

CHAPTER 1

INTRODUCTION

Mosquitoes, the small blood sucking and undesired insects that belong to order Diptera, family Culicidae, are considered as a vector for many diseases such as dengue fever, malaria, yelew fever, Japanese encephalitice, West Nile Virus and filariasis. They carry pathogenic organisms such as virus and parasites that cause diseases (Lehane 2005; Scudder & Cannings 2006; WHO 2014; Matthews 2011; WHO 1997).

The influence of mosquitoes on human health and well-being is greater than any other insects throughout the world. This is not only due to the diseases they transmit to humans but also the severe nuisance they cause (Pratt et al. 1963; Gandhi et al. 2013). The diseases transmitted by mosquito vectors are among the major contributors to human morbidity and mortality in many tropical and subtropical countries, and also to some extent, in temperate zones (WHO 1997; WHO 2014).

Each year, over one billion individuals are infected and over one million individuals die from vector-borne diseases with the majority attributed to mosquito-borne diseases (MBDs) (WHO 2014). The distribution of mosquito-borne diseases is affected by mosquito distribution. Mosquito distribution is mostly dependent upon the spatial distribution of larval breeding areas and spatial distribution of the preferred hosts as well as flight distance. These distributions vary in space and time (Gimnig et al. 2005). The geographic distribution and abundance of mosquito is governed by complex functioning phenomenon. However, environmental/climatic factors (temperature, relative humidity and rainfall) are the key determinants in the control over the mosquito vectors survival, production, development, abundance and distribution. In other words, mosquito abundance and distribution are affected by various environmental/climatic factors such as temperature, relative humidity and rainfall/precipitation. These environmental/climatic factors (temperature, relative humidity and rainfall) determine the occurrence of mosquito vectors by providing suitable condition for production, development rate and survival stages of larval and adult mosquito (Palaniyandi et al. 2014; P. Reiter 2001; Bashar & Tuno 2014; Zhou et al. 2007; Bayoh & Lindsay 2003; Barrera et al. 2006; Alshehri 2013; Alahmed 2012; Tian et al. 2015; Murty et al. 2010).

Many researchers reported the presence of mosquito-borne diseases (MBDs) such as dengue fever (Aziz et al. 2014; El-Gilany et al. 2010; Fakeeh & A. M. Zaki 2003; H. M. Khormi & Kumar 2013), malaria (Al-Tawfiq 2006; Bashwari et al. 2001; H. M. Khormi & Kumar 2013) and rift valley fever (Al-Qabati & Al-Afaleq 2010; Madani et al. 2003; Flick & Bouloy 2005; H. M. Khormi & Kumar 2013) in many parts of KSA. In addition to this, recent studies also indicated the presence and the increasing number of medically important mosquito vectors in Eastern Province, Saudi Arabia (Alahmed 2012; Ahmed et al. 2011) that poses a major concerns to investigate the relationship between mosquito abundance and climatic factors (temperature, relative humidity and rainfall), and mapping of their larval breeding sites for effective mosquito control.

Geographic Information System (GIS) is currently widely used application in modelling and mapping of public health issues, especially when dealing with mosquito control activity (Rydzanicz et al. 2011). The availability of up-to-date map of mosquito vector distribution play a major role in short and long term control programs to be implemented in the current and future mosquito control programs. GIS together with GPS (Global Positioning System) or remote sensing was used in many mosquito control activities in different countries. The employment of GIS facilitates the identification of the location and size of mosquito larvae breeding sites, update thematic map distribution, select type of insecticide to be used and apply environmental friendly mosquito control measures (M Palaniyandi 2014b; Zou et al. 2006; Rydzanicz et al. 2011) .

Mapping mosquito distribution, larvae breeding sites, MBDs distribution and spatial analysis and modelling of mosquito vector distribution are highly important and play a vital role in the design and implementation of effective mosquito control programs at global, regional, national and local levels (M Palaniyandi 2014a, 2014b; Palaniyandi et al. 2014; Palaniyandi & Nagarathinam 1997; Mushinzimana et al. 2006; Rydzanicz et al. 2011; Zou et al. 2006).

The influence of environmental factors (temperature, relative humidity and rainfall) on the production, development rate and survival stages of larval and adult mosquito have been investigated in many different studies. In addition, several studies have studied the relationship between environmental/climatic factors (temperature, humidity and rainfall) and mosquito vector abundance (P. Reiter 2001; Bayoh & Lindsay 2003; Barrera et al. 2006; Alshehri 2013; Alahmed 2012; Tian et al. 2015; Murty et al. 2010). However, there is no study done that investigated the relationship between mosquito abundance and environmental factors (temperature, relative humidity and rainfall) in the Eastern Province, Saudi Arabia. Therefore, the objective this study was to map the mosquito larvae breeding sites using GIS application and determine the relationship between mosquito abundance and environmental/climatic factors (temperature, relative humidity and rainfall) in the Eastern Province, Saudi Arabia.

1.1. Background and Problem Statement

Mosquitoes are unwanted notorious, small flying insects having four distinct life cycle stages (eggs, larvae, pupae and adult). The life cycle of mosquitoes is mainly dependent on water. Mosquitoes can present and develop in a wide range of habitats (Byun & Webb 2012; Eldridge 2008; Seligson 2010), and the specific breeding place varies with mosquito species. However, the most common breeding sites are stagnant waters, marshes, flood waters, brackish water, slow-moving streams, ditches, woodland pools, and around the edges of lakes. They can also breed in any place that holds water such as rain barrels, tree cavities, tin cans, fish ponds, catch basins, old tires and guttering except in marine environment having high salt concentration (Rueda 2008; Williams et al. 2010).

The abundance and distribution of mosquito vectors are governed by various biotic and abiotic factors and their interactions as well as the control measures taken. The rainfall, temperature, humidity, and surface water are among the most important abiotic factors that influence the abundance and distribution of mosquito vectors while the biotic factors that constrain the abundance and distribution of insects include: the vegetation, humans and animals. On the other hand, the control measures also limit the abundance and distribution of insects by avoiding breeding sites, larviciding of breeding sites and adulticiding with insecticides (Savopoulou-Soultani et al. 2012; Ceccato et al. 2005).

Mosquitoes have played a great role in transmitting deadly diseases in the history of human being (Goddard 2003). Mosquito species such as Anopheles, Aedes, Culex and Mansonia are well known mosquito vectors involved in biting and transmission of infectious diseases to humans and animals, in different parts of the world (Rueda 2008). Similarly, many mosquito vectors that carry parasitic and arboviral diseases also exist in Kingdom of Saudi Arabia. A study done by Khater et al. (2013) in three regions of Saudi Arabia (Makkah, Al-Baha, and Jezan) revealed vectors of medical importance such as Anopheles arabiensis and Anepheles sergenti as vectors of malaria, and *Culex tritaeniorhynchus*, *Culex quinquefasciatus* and *Aedes aegypti* as vectors of arboviral diseases. Similarly, a study done in Al- Madinah, Saudi Arabia identified *Culex pipiens* as a potential danger for transmission of West Nile Virus (I et al. 2008).

Ahmed et al. (2011) also identified *Aedes caspius*, *Anepheles multicolor*, *Culex perexiguus*, and *Culex pipiens* as important vectors of diseases in Al-Ahsa district. Other study done in eastern province of Saudi Arabia also showed the presence of medically important diseases vectors such as *Anopheles gambiae, Anopheles fluviatilis, Anopheles stephensi, Anopheles multicolor, Anopheles sergentii, Culex perexiguus, Culex pipiens, Culex quinquefasciatus, Culex tritaeniorhynchus*, and *Aedes caspius* (Alahmed 2012).

Mosquito-borne diseases (MBDs) are the results of the interaction of four aspects: the pathogens (parasite/virus), the mosquito vector, the human host and the environment. This implies that the breeding environment, abundance and survival rate of mosquitoes, and duration of the extrinsic incubation period together with the possibility of bite off human host determine the risk of mosquito-borne diseases, the rate of diseases transmission, and seasonal patterns (Ceccato et al. 2005). Malaria, dengue fever, rift valley fever (RVF), bancroftian filariasis and West Nile Virus are among deadly mosquito borne diseases that exist in different parts of the kingdom (H. Khormi & Kumar 2013; DPMIAC 1999).

Several mosquito-transmitted diseases have re-emerged and spread to new parts of the world within the past two decades, threatening the majority of the world's population. The spread of these diseases is attributed to the increasing number and spread of mosquitoes worldwide as a result of environmental changes such as changes in climate, ecosystem and patterns of land use. Besides, the rapid and growing movement of people and goods also play a role in the spread of mosquitoes and their diseases. In the previous times, mosquito-borne diseases were considered as a problem of tropical countries but now they become a greater threat to global public health, both in terms of percentage of population affected and geographical spread (WHO 2014).

1.2. Motivation and Significance of the Study

Environment is the main breeding site for mosquito species that transmit the deadly diseases. Mosquito-borne diseases (MBDs) are environmental diseases since the vectors require particular environmental conditions or specific sites with surface water for reproduction, relative humidity for survival of mosquito, and temperature for development rates of both the vector and parasite/virus populations. Mosquito vectors are a serious concern globally since they carry and spread environmental vector-borne diseases to many parts of the world (Ceccato et al. 2005; Kaya et al. 2014).

MBDs are not fully controlled by medicine or treating infected individuals alone. Effective strategy that breaks the chain of diseases transmission is the key to control these diseases. For this reason, understanding the spatial relationship between diseases vectors and their environmental factors is very crucial for effective mosquito control. Environmental factors are spatial factors that combine location with attribute data, which include the land, vegetation, rivers, streams, climate, rainfall, temperature, humidity, surface water, water quality, soil type, elevation and others. These factors strongly influence the reproduction and spread of mosquito vectors. In this context, there was a need to understand the relationship between mosquito vectors and the environmental/climatic factors (temperature, relative humidity and rainfall) and mapping of larval breeding habitat using GIS application for active mosquito control since the previous studies only explored diseases' clinical and laboratory aspects, and use of insecticide for mosquito control.

In addition, GIS application for mosquito control and to study mosquito-borne diseases is in its infancy in Saudi Arabia (H. Khormi & Kumar 2013). Besides, there is no documented GIS database for the study area and recent studies demonstrated the presence of mosquito vectors in the area that can cause a great health problem which require mosquito control (Ahmed et al. 2011; Alahmed 2012). Therefore, this study was proposed to close the existing gaps by exploring the relationship between climatic factors (temperature, relative humidity and rainfall) and mosquito abundance, and mapping the potential hotspots of mosquito larvae breeding sites using GIS application in order to assist public health managers, program managers, policy makers and decision makers implement effective control programs in current and future mosquito control programs before devastating problem takes place.

1.3. Study Objectives

The following are the study objectives

1.3.1. General objective: The main objective of this study was to map mosquito larvae breeding sites using GIS application and determine the relationship between mosquito abundance and climatic factors (temperature, relative humidity and rainfall) in Eastern province, Saudi Arabia.

1.3.2. Specific objectives:

- Determine the correlation between climatic factors (temperature, rainfall and relative humidity) and larval and adult mosquito abundance
- Identify and map potential hotspots suitable for mosquito larvae breeding
- Develop risk maps for mosquito control

CHAPTER 2

LITERATURE REVIEW

2.1. Global Distribution of Mosquito Species

Insects are abundant which found everywhere from desert to rain forests, from the poles to the equator and from the surface of the sea to the highest peaks. They have been around on this planet for more than 400 million years (McGavin 1997). Mosquitoes are the most common insects that belong to family Culicidae. Globally, there are around 3,500 different mosquito species (140 subgenera in 42 genera) , of which a couple of hundred bite humans (Seligson 2010; Fang 2010). The distribution of mosquitoes is almost worldwide, they are found throughout tropics, subtropics and temperate regions. However, they are not present in Antarctica and in a few islands (Rueda 2008).

Mosquito species diversity varies among different geographical regions of the world. Neotropical region has the greatest diversity of mosquito species (1069), followed by Oriental (1061 species), Afrotropical (795 species), Australasian (764 species), Palaeractic (492 species) while the Nearctic region (178 species) has the lowest species diversity of the total 3492 known mosquito species (Rueda 2008). Middle East is located in both Palaeractic and Afrotropical regions.

2.2. Mosquito Distribution in the Middle East

The Middle East which is found in both Palaeractic and Afrotropical regions contains different diversity of mosquito species. It includes Bahrain, Saudi Arabia, Qatar, United Arab Emirates, Yemen, Oman, Kuwait, Lebanon, Cyprus, Egypt, Palestine, Syria, Iran, Iraq, Israel, Jordan and Turkey. Middle East covers a land area of more than 6 million square kilometers. The topography is mainly lowlands or plateaus, with several mountain ranges in the north and in coastal area. The overall climatic condition is characterized as arid, with annual rainfall that range from 640 mm in Turkey and Lebanon to 80 mm in most parts of Qatar and Yemen. However, the average annual rainfall for most of Middle East countries is less than 230 mm (DPMIAC 1999).

The most common mosquito species found in the Middle East include: *Aedes: Aedes aegypti, Ae. Annulipes, Ae. Caballus, Ae. caspius, Ae. communis, Ae. detritus, Ae. dorsalis, Ae. echinus, Ae. excrucians, Ae. flavescens, Ae. geniculatus, Ae. grantii, Ae. lepidonotus, Ae. mariae, Ae. nigrocanus, Ae. pulchritarsis, Ae. refiki, Ae. rusticus, Ae. vexans and Ae. vittatus, Anopheles: Anopheles algeriensis, An. apoci, An. azaniae, An. claviger, An. cinereus*, *An. coustani*, *An. culicifacies, An. demeloni, An. d'thali, An. fluviatilis, An. gambiae arabiensis, An. hyrcanus, An. maculipennis, An. marteri sogdianus, An. martinius, An. messeae, An. moghulensis, An. multicolor, An. paltrinierii, An. pharoensis, An. plumbeus, An. pretoriensis, An. pulcherrimus, An. rhodesiensis rupicola, An. sacharovi, An. sergentii, An. squamosus, An. stephensi, An. subalpinus, An. subpictus, An. superpictus, An. tenebrosus and An. turkudi, Coquillettidia: Coquillettidia buxtoni and Cq. Richardii, Culex: Culex antennatus, Cx. Arbieeni, Cx. Bitaeniorhynchus, Cx. Decens, Cx.*

Deserticola, Cx. Duttoni, Cx. Hortensis, Cx. Judaicus, Cx. laticinctus, Cx. martini, Cx. mattinglyi, Cx. mimeticus, Cx. modestus, Cx. perexiguus, Cx. pipiens molestus, Cx. pipiens pipiens, Cx. p. quinquefasciatus, Cx. pseudovishnui, Cx. pusillus, Cx. saliburiensis, Cx. simpsoni, Cx. sinaiticus, Cx. sitiens, Cx. territans, Cx. thallasius, Cx. theileri, Cx. tigripes, Cx. torrentium, Cx. tritaeniorhynchus and Cx. univittatus, Culiseta: Culiseta annulata, Cs. Fumipennis, Cs. longiareolata, Cs. morsitans, Cs. subochrea, and *Uranotaenia: Uranotaenia unguiculata* (DPMIAC 1999).

Mattingly & Knight (1956) also studied mosquito larvae distribution in the Arabian Peninsula and reported 46 species and subspecies that belong to four genera: *Anopheles (17 species): Anopheles coustani Laveran, Anopheles coustani var. tenebrosus Donitz, Anopheles cinereus Theobald, Anopheles culicifacies Giles, Anopheles culicifacies ssp. adenensis Christophers, Anopheles demeilloni Evans, Anopheles dthali Patton, Anopheles jiuviatilis James, Anopheles gambiae Giles, Anopheles multicolor Cambouliou, Anopheles pharoensis Theobald, Anopheles pretoriensis (Theobald), Anopheles pulcherrimus Theobald, Anopheles rhodesiensis ssp. rupicolus Lewis, Anopheles sergenti Theobald, Anopheles stephensi Liston* and *Anopheles turkhudi Liston, Culiseta (1 species): Culiseta longiareolata (Macquart), Aedes (8 species): Aedes caballus Theobald, Aedes caspius Pallas, Aedes aegypti Linnaeus, Aedes granti Theobald, Aedes vittatus Bigot, Aedes arabiensis (Patton), Aedes hirsutus var. adenensis Edwards* and *Aedes natronius Edwards,* and *Culex (20 species): Culex tigripes de Grandpre & de Charmoy, Culex {Neoculex) arbieeni Salem, Culex salisburiensis Theobald, Culex sp. Indet, Culex nebulosus Theobald, Culex pusillus Macquart, Culex decens Theobald, Culex duttoni Theobald, Culex ethiopicus Edwards, Culex laticinctus Edwards, Culex mattinglyi Knight, Culex* *pipiens Linnaeus, Culex pipiens ssp. fatigans Wiedemann, Culex pipiens var. molestus Forskal, Culex simpsoni Theobald, Culex sinaiticus Kirkpatrick, Culex sitiens Wiedemann, Culex theileri Theobald, Culex tritaeniorhynchus Giles* and *Culex univittatus Theobald.*

2.3. Mosquito Distribution in Saudi Arabia

In Saudi Arabia mosquito vectors are found in many parts of the country. Many investigators have been studied the ecological distribution and abundance of mosquitoes (Diptera: Culicidae) in Saudi Arabia. Mattingly & Knight (1956) collected 18 species belonging to 3 genera from Saudi Arabia: *Anopheles (7 species): Anopheles cinereus, Anopheles multicolor, Anopheles stephensi, Anopheles coustani, Anopheles turkhudi, Anopheles gambiae* and *Anopheles sergenti, Aedes (3 species): Aedes aegypti, Aedes arabiensis and Aedes caspius,* and *Culex (8 species): Culex laticinctus, Culex tritaeniorhynchus, Culex sitiens, Culex sinaiticus, Culex pusillus, Culex tigripes, Culex pipiens* and *Culiseta longiareolata.*

Al Ashry et al. (2014) studied the fauna of mosquito larvae and reported a total of 31 species of 8 genera in Asir region, Saudi Arabia: *Anopheles (7 species), Culex (17 species), Lutzia (2 species), Aedimorphus (1 species), Fredwardsius (1 species), Ochlerotatus (1 species), Stegomyia (1 species)* and *Culiseta (1 species)*. The species reported were *Anopheles arabiensis Patton, Anopheles cinereus Theobald, Anopheles culicifacies Giles s.l, Anopheles dthali Patton, Anopheles fluviatilis James, Anopheles multicolor Cambouliu, Anopheles sergentii Theobald, Anopheles turkhudi Liston, Culex decens Theobald, Culex duttoni Theobald, Culex laticinctus Edwards, Culex mattinglyi Knight, Culex mimeticus Noè, Culex perexiguus Theobald, Culex pipiens L, Culex quinquefasciatus Say, Culex* *simpsoni Theobald, Culex sinaiticus Kirkpatrik, Culex theileri Theobald, Culex tritaeniorhynchus Giles, Culex (Culiciomyia) nebulosus Theobald, Culex (Eumelanomyia) wigglesworthi Edwards, Culex (Maillotia) arbieeni Salem, Culex (Maillotia) salisburiensis Theobald, Culex (Oculeomyia)bitaeniorhynchus Giles, Lutzia (Metalutzia) tigripes (de Grandpre & de Charmoy), Aedimorphus vexans arabiensis (Patton), Fredwardsius vittatus (Bigot), Ochlerotatus (Oc.) caspius (Pallas), Stegomyia (St.) aegypti (L.),* and *Culiseta (Allotheobaldia) longiareolata Macquart.*

Abdullah & Merdan (1995) also identified 9 mosquito species of 4 genera: *Anopheles (4 species): Anepheles arabiensis, Anepheles sergentii, Anepheles multicolor* and *Anepheles tenebrosus, Culex (3 species): Culex pipiens, Culex quinquefaciatus* and *Culex theileri, Aedes (1 species): Aedes caspius,* and *Culiseta (1 species): Culiseta subochre*a, in a mosquito larval survey conducted in the Southwestern region of Saudi Arabia. In Al-Madinah, Saudi Arabia, seven Culex species were collected which include *Culex pipiens, Culex quinquefaciatus, Culex duttoni, Culex decens, Culex laticinctus, Culex sinaiticus* and *Culex univittatus* (I et al. 2008).

Similarly, a study done in Jezan province revealed 16 mosquito species that belong to 7 genera: *Culex (7 species): Cx. sitiens Wiedmann, Cx. decens Theobald, Cx. bitaeniorhynchus Giles, Cx. pipiens Linnaeus, Cx. quinquefasciatus Say, Cx. sinaiticus Kirkpatrick,* and *Cx. tritaeniorhynchus Giles, Anopheles (4 species)*: *An. d'thali Patton, An. pretoriensis Theobald, An. Arabiensis Patton,* and *An. turkhudi Liston, Aedes (1 species): Ae. caspius Pallas, Stegomyia (1 species): St. aegypti Linnaeus, Aedimorphus (1 species): Am. vexans arabiensis Patton, Lutzia (1 species): L. (Metalutzia) tigripes de Grandpre & de Charmoy* and *Culiseta (1species): Cs. longiareolata Macquart* (Bakr et al. 2014).

In the eastern region of Saudi Arabia, Alahmed (2012) recorded 25 species representing five genera: *Anepheles (13 species), Culex (9 species), Aedes (1 species), Culiseta (1 species*) and *Uranotaenia (1 species)*. The mosquito species that were collected include: *Anopheles cinereus Theobald, Anopheles coustani Laveran, Anopheles d'thali Patton, Anopheles fluviatilis James, Anopheles gambiae Giles, Anopheles multicolor Cambouliu, Anopheles pretoriensis Theobald, Anopheles rhodesiensis Lewis, Anopheles sergentii Theobald, Anopheles stephensi Liston, Anopheles subpictus Grassi, Anopheles superpictus Grasssi, Anopheles tenebrosus Donitz, Culex laticinctus Edwards, Culex perexiguus Theobald, Culex pipiens Linnaeus, Culex pusillus Macquart, Culex quinquefasciatus Say, Culex simpsoni Theobald, Culex torrentium Martini, Culex tritaeniorhynchus Giles, Culex univittatus Theobald, Aedes caspius Palls, Culiseta longiareolata Macquart* and *Uranotaenia unguiculata Edwards.*

Ahmed et al. (2011) reported five mosquito species which belong to three genera: *Aedes (1 species), Anopheles (1 species)* and *Culex (3 species)* in the Al-Ahsaa district located in the eastern region of Saudi Arabia. These species were *Aedes caspius Pallas, Anopheles multicolor Cambouliu, Culex perexiguus Theobald, Culex pipiens L.,* and *Culex pusillus Macquart.*

2.4. Climatic Factors Influencing Mosquito Distribution and Abundance

The type and abundance of larval habitat is greatly influenced by environmental/climatic factors (precipitation, temperature, humidity, climatic changes, presence of plants and location). In addition, these factors influences the larval stages, number of mosquito species, and the life span, the behavior and development of adults with the direct implication for disease transmission (Khater et al. 2013; Juliano 2009; Murdock et al. 2012).

Suryanarayana Murty et al. (2010) found temperature and rainfall were correlated with per man hour (PMH) mosquito density while humidity inversely correlated with PMH density. They also found that high precipitation (rainfall) increases number of larval habitats and mosquito population size by creating new larval breeding sites. In addition, they found high mosquito density at optimum temperatures (22-34°C) with relative humidity (42.7-69.6%) in both rural and urban areas.

Alshehri (2013) also found strong correlation between mosquito density and climatic factors of temperature and relative humidity but not with rainfall. Similarly, Minakawa et al. (2002) found climatic factors (temperature and humidity/moisture) strongly affected the distribution and abundance of mosquito while the effect of rainfall (dry season and rainy) on abundance and distribution of mosquito vectors varies among mosquito species. Specifically, the study showed that temperature influences density of An.gambiae, An.arabiensis, and An. funestus while humidity is positively associated with An.gambiae.

2.4.1. Temperature

Temperature is one of the most important factors that influence the abundance, activity and presence of mosquito in temporary and permanent habitats. It has an effect on both the development of the vector and the parasite. It affects the development time from egg to adult (such as development rate of juvenile, duration of gonotrophic cycle, survivorship stages of both juvenile and adult) at optimum temperature as well as lower and upper temperature limits. Temperature also affects the extrinsic incubation period of the parasite (Bayoh & Lindsay 2003; Costa et al. 2010; Tun-Lin et al. 2000; Ceccato et al. 2005; Byun & Webb 2012).

2.4.2. Rainfall

Rainfall has also the most significant influence on mosquito populations. However, the impact of rainfall varies with the amount and temporal distribution of rainfall. Persistent and excessive rainfall helps create numerous mosquito breeding sites in low lying areas as well as maintaining permanent mosquito breeding sites. In contrary, heavy rainfall may also have opposite effect by decreasing the temperature and by flushing out mosquito larvae from small breeding sites (Byun & Webb 2012; Ceccato et al. 2005).

2.4.3. Humidity

The other important factor that influences the survivorship of adult mosquitoes is humidity which is influenced by both temperature and rainfall (Byun & Webb 2012). Variation in humidity affects both the number of females laying eggs and the number of eggs laid (Costa et al. 2010). It also influences the feeding frequency and metabolic rate of adult mosquitoes (Alshehri 2013). The lifespan of mosquito is also influenced by humidity that is survivorship increases with increasing humidity, consequently, laying more eggs and higher probability to transmit disease causing pathogens (Paul Reiter 2001).

2.5. Global Overview of Mosquito-Borne Diseases

Globally, hundreds of millions of mosquito borne diseases occur every year, representing a major threat to global public health (WHO 2006; WHO 2014). The most common diseases that are transmitted by mosquitoes include: malaria, dengue, filariasis, yelew fever, Japanese encephalitis, chikungunya, rift valley fever and West Nile Virus (WHO 1995; WHO 2014; Pratt et al. 1963; Seligson 2010).

Malaria which is one of the deadly mosquito-borne diseases is mainly transmitted by Anopheles gambiae and Anopheles funestus while dengue is transmitted by Ae.aegypti, filariasis by Culex, Anopheles and Aedes, yelew fever by Aedes aegypti, Japanese encephalitis by Culex tritaeniorhynchus, Chikungunya by Ae. aegypti and Ae. albopictus, and West Nile Virus is transmitted by Culex pipiens and Culex tarsalis (WHO 2014).

The prevalence of these diseases is increasing from time to time. In 2012, malaria accounts for 207 million cases and for an estimated deaths of 627, 000 individuals worldwide (WHO 2013; WHO 2014). Similarly, more than 2.3 million cases of dengue fever were reported globally in 2010. Over 40% of the world population (more than 2.5 billion people) is also at risk of dengue globally. In addition, there are about 200, 000 cases of illness and 30,000 deaths due to yelew fever, and 50, 000 cases and 10, 000 deaths from Japanese encephalitis every year. Currently, there are more than 120 million people infected by lymphatic filariasis, of these about 40 million people are disfigured and incapacitated by the disease. Around 1.4 million cases of chikungunya were also reported in 2006 from the WHO south-east Asia region (WHO 2014).

2.6. Mosquito-Borne Diseases in Saudi Arabia

Malaria is one of the mosquito-borne diseases transmitted by Anopheles mosquito. The risk of malaria is low to moderate in kingdom of Saudi Arabia (DPMIAC 1999). The southern part of the country is an epidemic area for malaria, with 38, 613 cases reported from Jizan and Asir regions between 1997 and 2002. The second malarious area is the western part of Saudi Arabia, with 12, 984 cases reported from Al Taif, Makkah, Jeddah, Al Gonphoda and Theriban regions. The third area is Al Baha with 2,148 cases reported from 1997 to 2002 (H. Khormi & Kumar 2013). On the other hand, eastern, central and northern provinces are considered as malaria-free areas or oldest areas of malaria endemic. However, the presence of mosquito vectors in malaria-free area and imported malaria (immigrant) cases have the potential to initiate indigenous malaria transmission (DPMIAC 1999).

Al-Tawfiq (2006) studied the epidemiology of travel-related malaria in a non-malarious area in Saudi Arabia and found 56 cases of imported malaria diagnosed at Saudi Aramco Medical Services Organization in Dhahran, Eastern province of Saudi Arabia, with the majority of cases infected outside the kingdom (mainly from Pakistan, India and Sudan) while the remaining acquired in the kingdom mainly from south and southwest of Saudi Arabia but not from eastern province. However, the study suggested the imported malaria in the presence of mosquito vector may pose serious health problem in the region unless effective treatment of cases and mosquito control is carried out.

A clinical case-series study about epidemiological profile of malaria in a university hospital in the eastern province also showed 602 confirmed cases diagnosed at King Fahad Hospital of the University from 1990 to 1999. Of the cases, 42% were Saudis, and the most common species diagnosed were Plasmodium falciparum and Plasmodium vivax (Bashawri et al. 2001). In Saudi Arabia, Anopheles mosquito species such as An. arabiansis, An. fluviatilis, An. pharoensis, An. pulcherrimus, An. sergentii, An. stephensi and An. superpictus are the primary vectors responsible for malaria transmission (DPMIAC 1999).

Dengue fever is another mosquito-borne disease transmitted by Aedes aegypti (primary vector) in Saudi Arabia. Aedes caspius and Aedes albopictus are also potential vectors for dengue fever transmission in the kingdom (DPMIAC 1999). Dengue fever case was first identified in Jeddah, Saudi Arabia, in 1994. According to the study, dengue virus infection was confirmed in 319 (31.3%) cases from a total of 1020 suspected clinical cases examined by laboratory methods from February 1994- December 2002 (Fakeeh & A. Zaki 2003).

Aziz et al. (2014) reported 4411 cases of dengue, with 8 cases of mortality in Jeddah and Makkah in 2013. The highest (1272) and lowest (37) number of dengue cases was reported in May and September, 2013 respectively. The study showed the growing number of cases despite the availability of adequate financial resources to establish effective control measures for dengue vector. (El-Gilany et al. 2010) also reported 71 cases of dengue fever and one death in Holy City of Mecca, Saudi Arabia.

Rift valley fever is viral zoonoses transmitted by mosquito vectors. It affects both human and domestic animals (ruminants). Rift valley fever was spread to Arabian Peninsula in 2000 and caused two simultaneous outbreaks in Yemen and Saudi Arabia. This was the first appearance of rift valley fever outside of the African continent (Flick & Bouloy 2005). In Saudi Arabia, cases of rift valley fever are found in Jizan, Makkah, Asir, Riyadh, eastern and Najran regions. The highest number of cases was found in Jizan and Asir during the first occurrence of the diseases in 2000 (H. Khormi & Kumar 2013).

Madani et al. (2003) studied the epidemiological, clinical and laboratory characteristics of the Rift Valley fever (RVF) epidemic in Saudi Arabia from August 26, 2000 - September 22, 2001 and found a total of 886 reported cases of rift valley fever. From the 834 cases for which laboratory results were available, they found that 81.9% of the reported cases were laboratory confirmed, of which 51.1% were positive for only RVF immunoglobulin M, 35.7% were positive for only RVF antigen, and 13.2% were positive for both.

Al-Qabati & Al-Afaleq (2010) also studied the presence and prevalence of the rift valley fever among domestic ruminants in al- Hasa Oasis. They collected a total of 598 serum samples from sheep, goats, cattle and camels during 2007. The low prevalence of intra-herd, the scattered distribution of the two seropositives, and the absence of both anti-RVF IgM antibody and RVF-incidence in the sentinel herd suggested that the seropositive animals were infected from outside of the oasis rather than from an internal oasis infection. This study also showed the readiness of the region for possible outbreak of rift valley fever.

Culex tritaeniorhynchus, Culex pipiens, Culex perexiguus, Culex quinquefasciatus, Aedes casipus, Aedes vexans and Culex antennatus, Culex zombaensis are vectors of rift valley fever. Of these, the first five vectors are prevalent in eastern province. Culex tritaeniorhynchus and Aedes vexans are the primary vectors for rift valley fever transmission.

2.7. Mosquito Control

Mosquito control is an essential and basic function of public health. However, it is a multi-faceted issue and requires the involvement of not only the health sector but also individuals, families, and their neighbors (ASTHO 2005), and other governmental and nongovernmental organizations. Mosquitoes can be controlled mainly by larvicidal and adulticidal approaches. However, their highly diversified breeding sites are the main challenges for mosquito control. For this reason, effective mosquito control requires understanding of mosquito distribution, identification of mosquito larvae breeding habitats (Gandhi et al. 2013) and the relationship between mosquito vectors and environmental/climatic factors.

Integrated mosquito control program includes reduction of mosquito breeding sites (point source reduction), regular larviciding of breeding sites that cannot be eradicated, and adulticiding only when appropriate (Goddard 2003). Chemical and biological control methods are used for mosquito control but in most cases chemical insecticides are highly utilized.

Information on the spatial relationship between mosquito vectors and environmental factors is a key for effective mosquito control (Zhou et al. 2007). Knowing mosquito larvae habitat and its physical characteristics which provide the image of larvae species existence in certain areas is of great importance. Identification of potential area together with the best conditions that favors for the breeding of mosquito larvae helps for effective mosquito control programs (Vanlalruia et al. 2014). Monitoring and controlling mosquito larvae by understanding the environmental factors that favors breeding is also the best way to avoid the impact of mosquito-borne-diseases (Khormi & Kumar 2011).

The need of mosquito control is not doubtable and if proper control measures don’t take now, mosquito vectors will continue to spread the diseases plaguing extremely serious impact for the entire world. In addition, the absence of vaccines for many mosquito-borne diseases and the growing drug resistance make the condition more complex. Mosquito control plays a very important role in breaking diseases transmission by avoiding breeding sites, eradicating both larvae and adult mosquito using insecticides (WHO 2014; Goddard 2003).

2.8. Geographic Information System (GIS)

Geographic Information System (GIS) is a tool that contains a set of computer hardware, software and geographic data designed to captured, stored, retrieve, update, manage, manipulate, analyze, and display geographically referenced information. It is a useful tool for sketching maps in various scales and projections, having excellent instrument for data analysis and integration due to its ability to identify spatial connections between different information layers (Burrough 1986; Maguire 1991; Goodchild 1992; Rydzanicz et al. 2011).

Nowadays, geographic information system is widely used technique for mapping, monitoring, measurement, modeling, management and assessment in several fields. It is used in research, industry and administrative activities by professionals in dealing with spatially related information. Similarly, the use of GIS is increasing in environmental and public health issues, especially in dealing with mosquito-vector control and mosquito-borne diseases (Kistemann et al. 2002; Rydzanicz et al. 2011; Glass et al. 1993).

2.9. Geographic Information System Application in Mosquito Control

The application of GIS is increasing dramatically from day to day to solve real world problems that involve an aspect of location. GIS application in public health, environmental management, transport, defense, utilities and business involves many aspects of spatial information. Similarly, GIS is useful technology for spatial correlation between health aspects and the environment, for example in mosquito control, environmental hazards and solid waste management, as well as between diseases and the environment such as mosquito-borne diseases since these health aspects or diseases have influenced by environmental factors and have spatial dimensions.

Geographic information system has many applications in mosquito control and to study mosquito-borne diseases since many of the factors that influence the distribution of mosquitoes and the diseases they transmit are spatially attributed. In this regard, this powerful tool has the ability to link spatial information (location and geometry data) between different information layers with the attribute data like ‘x’ and ‘y’ coordinates, larval and adult mosquito types, length and width of breeding site, waste types, distance to nearest house, temperature, rainfall and relative humidity. It gives the user with a better understanding of ecology, spatial data, and their relationships, that may not be clear without such advanced techniques of query, selection, analysis and display (Rydzanicz et al. 2011).

GIS may be used to map and analyze the spatial distribution of mosquitoes and to assess environmental factors that contribute to observed distribution. Comprehensive understanding of the factors that causes heterogeneities in mosquitoes distribution and MBDs can help to design effective and more efficient control programs that maximize the available limited resources (Gimnig et al. 2005). It is also used in pest control management (Hailey 2005)

GIS application alone or along with remote sensing and/or Global Positioning System (GPS) was employed in different mosquito control and mosquito-borne diseases studies (Rydzanicz et al. 2011b; Gandhi et al. 2013; Ceccato et al. 2005; M Palaniyandi 2014b; Chaikoolvatana et al. 2007; Palaniyandi et al. 2014; Gimnig et al. 2005; Thomson & Connor 2000; H. Khormi & Kumar 2013; Kistemann et al. 2002; Khormi & Kumar 2011; Ai-leen & Song 2000; S. Agarwal et al. 2012; Kazmi & Usery 2001; Nmor et al. 2013).

CHAPTER 3

METHODOLOGY

3.1. Study Area

Saudi Arabia is the twelfth biggest country in the world (DPMIAC 1999), with a land area of more than 2 million sq. km (Alyamani & Sen 1993). The climatic condition in almost all parts of Saudi Arabia is characterized as very hot, arid and desert climate. The inland temperature ranges from -2^{o}C during winter to 48^{o}C during summer. Temperature variation of 10^{o}C or more are common in the daytime. Generally, mountainous regions and coastal areas have summer temperatures a few degrees lower. Throughout the kingdom, winter (December to February) nights can be very cold, with temperatures infrequently falling below freezing, frost and snow may occur in mountainous areas. The amount of annual rainfall is low and erratic and generally decreases from north to south and west to east. It varies from 100-200 mm in the north to 100 mm in the South, except in the Asir (300 mm) (DPMIAC 1999).

The Eastern province of Saudi Arabia is located along the Arabian Gulf bordered by Northern Province to the north, Kuwait to northeast and Sultanate of Oman to the south. The study area is found between the Long 46^{o}– 55^{o}E and Lat. 20^{o}–28^{o}N, which include the study areas: Abu Main, Umm As Sahik, Safwa, Al-Awjam, Dammam, Al-Qatif and its surrounding area, Buqayq and Al-Sarar. These areas are selected due to diverse ecology and abundance of mosquito species.

Eastern province is generally divided into (1) the Northern plains which bordered with Hafar Al-Batin and Kuwait, (2) Summan plateau (northern and southern summan), an open plain adjacent to the Dahna sands (northern and southern Dahna), (3) the coastal lowlands (central and south coastal lowlands) and (4) the Rub'al-khali, the largest, continuous sand body in the world. Eastern province is characterized generally by arid climate with temperature rising from 15°C in January to a maximum of about 42 °C in August-September period. The average annual rainfall ranges from around 100 mm in the north and northeast during winter to less than 10 mm in Rub al-khali (Thomas 2012).

Several environmental factors influence the abundance and distribution of mosquito in the area. These factors include temperature, relative humidity and precipitation, the presence of palm gardens/vegetables that hold large volume of rainwater, widespread salt marshes and irrigation diches. Poor sanitary sewerage system in the areas also causes the accumulation of large volume of sewage water which serves as a good breeding habitat for mosquito in the study area (Alahmed 2012). 322 larvae breeding sites were assessed for the presence of mosquito larvae in eight locations. However, only 206 sites (64.0%) found positive with mosquito larvae. Those locations includes; Abu Main (5 sites), Umm As Sahik (19 sites), Safwa (10 sites), Al-Awjam (22 sites), Dammam (12 sites), Al-Qatif and its surrounding area (81 sites), Buqayq (32 sites) and Al-Sarar (25 sites). Those sites shown their diverse ecological characteristic and abundance of mosquito species (Figure 1, 2).

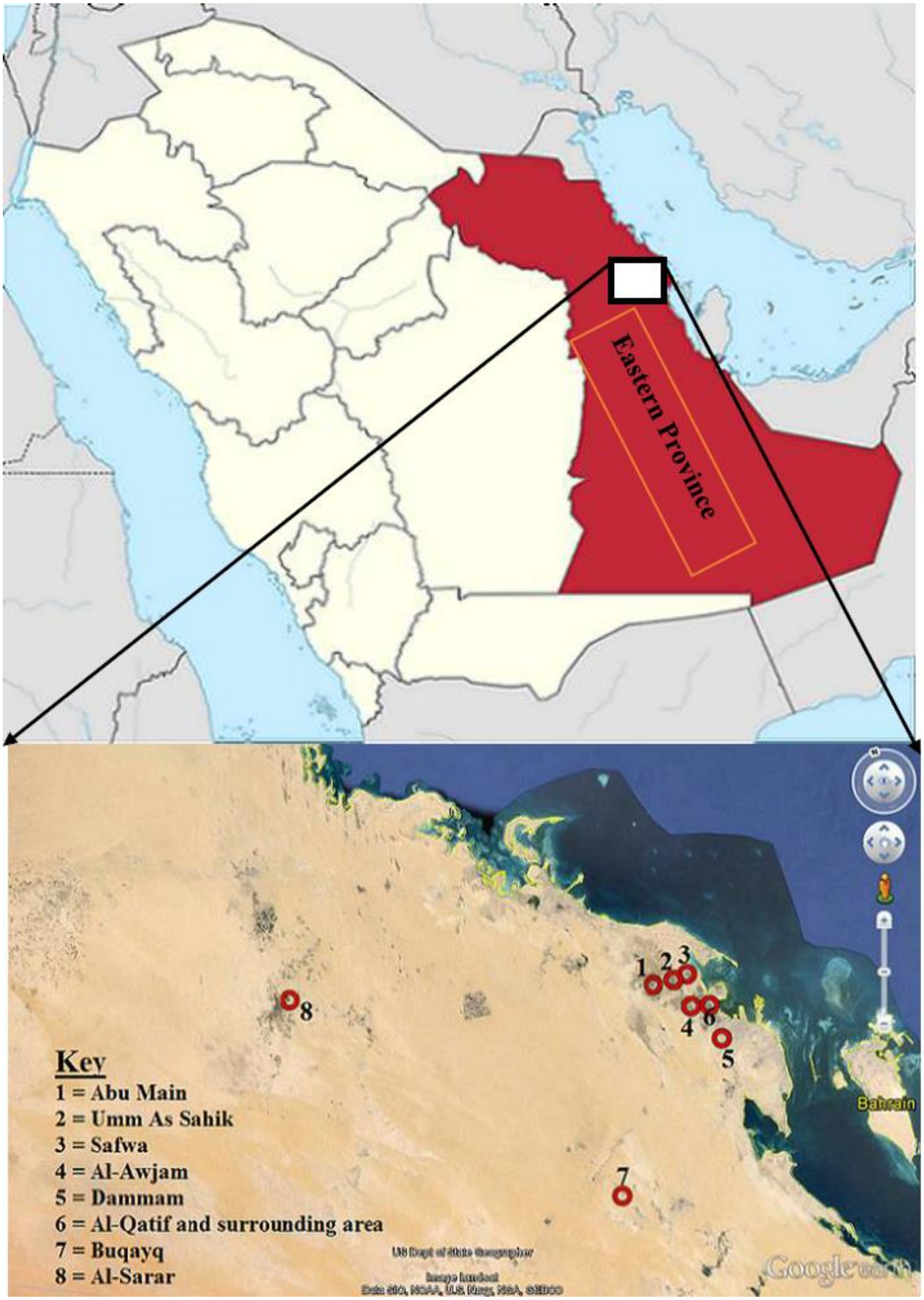

Figure 1. Map of Eastern Province, Saudi Arabia

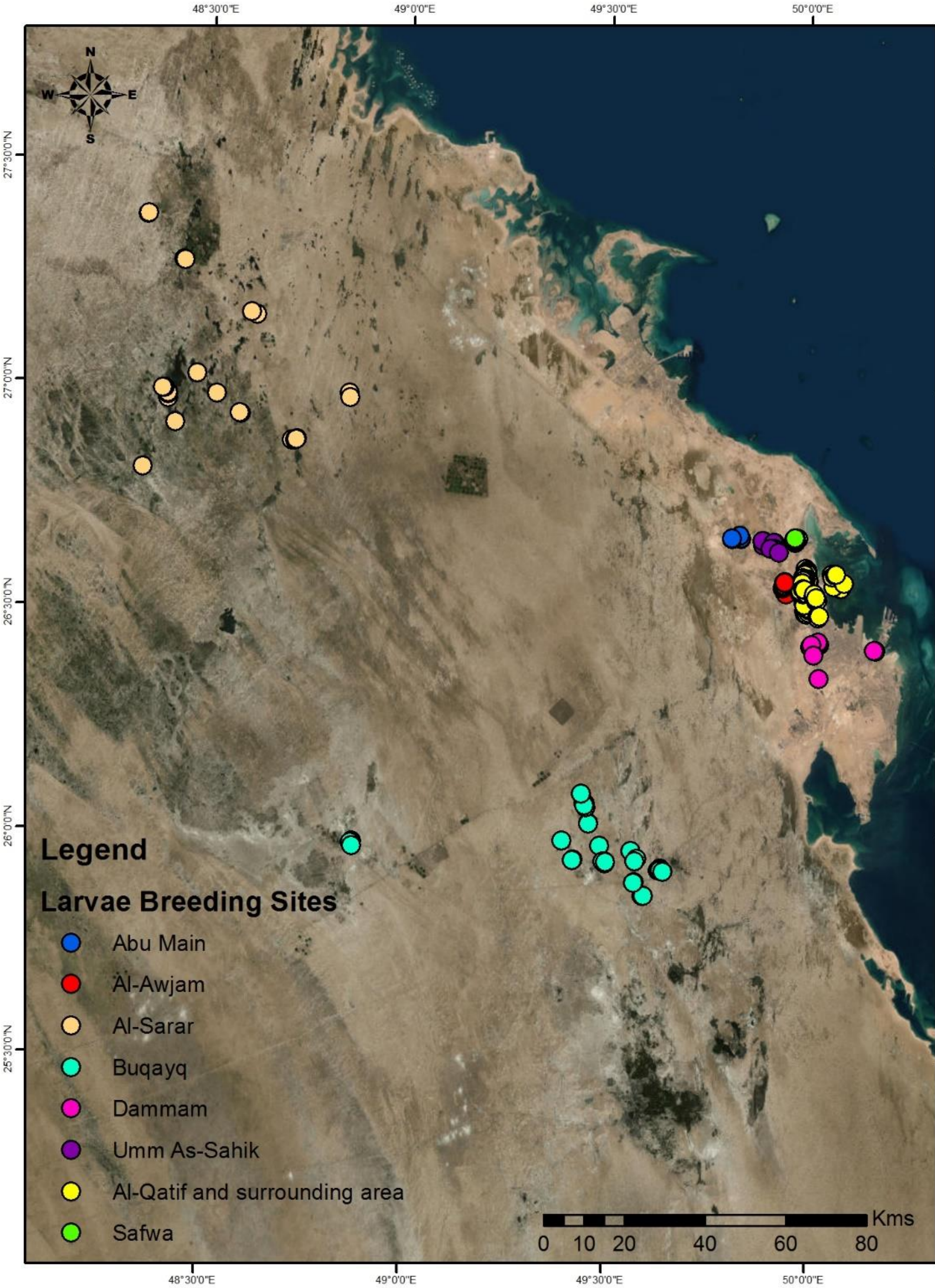

Figure 2. Larvae breeding habitat in each study sites in Eastern Province, Saudi Arabia, 2014

3.2. Data Collection

The primary and secondary data were collected during the study period. The primary data were directly collected from field observation while the secondary data were obtained from Ministry of Health (MOH) and Presidency of Meteorology and Environment (PME)

3.2.1. Field Data Collection

Field data collection was carried out together with team of mosquito prevention and control (General directorate of Health Affairs in Eastern Province) from February to April 2015 to collect spatial information and environmental variables: water surface/wetland area (width and length), presence of terrestrial and immersed vegetation, presence of algae, debris types (tires, plastics, papers, clothes), land use and land cover (farm land, pastureland, forest/vegetation and natural swamp) for each selected mosquito larvae habitat. The water surface area (length and width) and distance to the nearest house was estimated. The distance to the nearest house has categorized into 5 classes (i.e., 1= <100 m, 2 = 101-200 m, 3 = 201-400 m, 401 – 800 m, and 5 = > 800 m) by considering the flying distance after obtaining blood meal required for the egg development at the nearby villages, the mosquito may fly as far as 1-3 km for suitable habitat to breed. The coordinates of each selected breeding sites were recorded with a hand-held GPS (Geographic Positioning System) (Garmin Model Nuvi 50).

In addition, the presence and absence of mosquito larvae (larvae of Anopheles, Culex and Aedes) were checked for each selected breeding site by taking 3-5 scoops of water and the type of mosquito larvae was identified by naked eye and microscope, and recorded during field data collection period. Similarly, adult mosquito (Anopheles, Culex and Aedes) was captured using electric fly catchers and/or cow sheet (with spray) to check their presence (Alahmed 2012). For each breeding habitat field images was taken using normal hand-held camera. A checklist data collection format was also prepared for field observation (Table 1).

Table 1. Checklist data collection format for field data collection/field observation

S.No	**Name of place**	**Coordinates**		**Observation**						
		Latitude	Longitude	Larvae type	Size of Water body		Distance to the nearest house	Presence of vegetation	Waste type	Others
					Length	width				

3.2.2. Secondary Data

Number of mosquito larvae and adult mosquito for each selected sites collected by the team of mosquito prevention and control from January 2014 up to December 2014 were obtained from General Directorate of Health Affairs in Eastern province, Ministry of Health, Dammam, Kingdom of Saudi Arabia. The staff was composed of experienced persons with expertise in taking mosquito larvae samples, knowledge and skills in identifying the mosquito larvae types. In addition, data about climatic factors such as temperature, relative humidity, and rainfall for the study area were obtained from Presidency of Meteorology and Environment, Kingdom of Saudi Arabia for the period noted above.

3.2.3. **Materials Used**

Geographic Positioning System (GPS) [Garmin Model Nuvi 50] was used for recording the coordinates of each breeding sites. Scoops were used for taking water to check mosquito larvae. Electric fly catchers and/or cow sheet (with spray) were utilized to catch adult mosquito while camera was used for taking images during field observation.

3.3. Mapping Mosquito Breeding Sites

A map of Kingdom Saudi Arabia showing the governorate boundaries was used as a base map from ESRI to link all thematic data with spatial features in order to construct an accurate database of mosquito breeding sites in Eastern province, Kingdom of Saudi Arabia. In addition, attribute data such as the ‘x’ and ‘y’ coordinates, mosquito types, types of breeding site, size of water body (width and length), distance to the nearest house, presence of fish, algae and debris type (tires, plastics, papers, clothes) were set in the creation of the map disaster.

The latitude and longitude of the mosquito breeding habitats that is the x and y coordinates recorded using GPS [Garmin Model Nuvi 50] were exported to ArcGIS version 9.3 and then geo-referenced to develop GIS database. The existing and potential mosquito larvae breeding sites were represented by point location in the GIS map. The GIS map showed the geographical visualization of the mosquito larvae breeding sites in order to recognize specific areas with high larval abundance.

3.4. Study Design

Mosquito distribution and abundance is influenced by climatic/environmental factors (temperature, rainfall and humidity). Thus, this study was designed to map the spatial distribution of mosquito and determine the correlation between environmental/climatic factors and mosquito abundance.

3.5. Study Procedures

A systematic procedure was carried out to study mosquito distribution and abundance in Eastern Province, Saudi Arabia. Data were collected for breeding habitat, attribute data, larval and adult mosquito abundance, and climatic factors (temperature, relative humidity and rainfall) recorded daily and compiled monthly and annually. The data were analyzed graphically and statistically on monthly bases for each study site. To generate a map with layers, the effect of environmental/climatic factors: temperature, relative humidity, and rainfall was considered in order to develop the risk map. The first step was converting mosquito larvae habitat together with their attribute data into ArcMap layer accompanied with variables. The second step was identifying potential hotspots of mosquito larvae breeding sites. The final step was determining the buffer zone (buffer distance) to indicate or map mosquito risk areas from larvae breeding sites. The following figure shows the procedure followed during the study (Fig. 3).

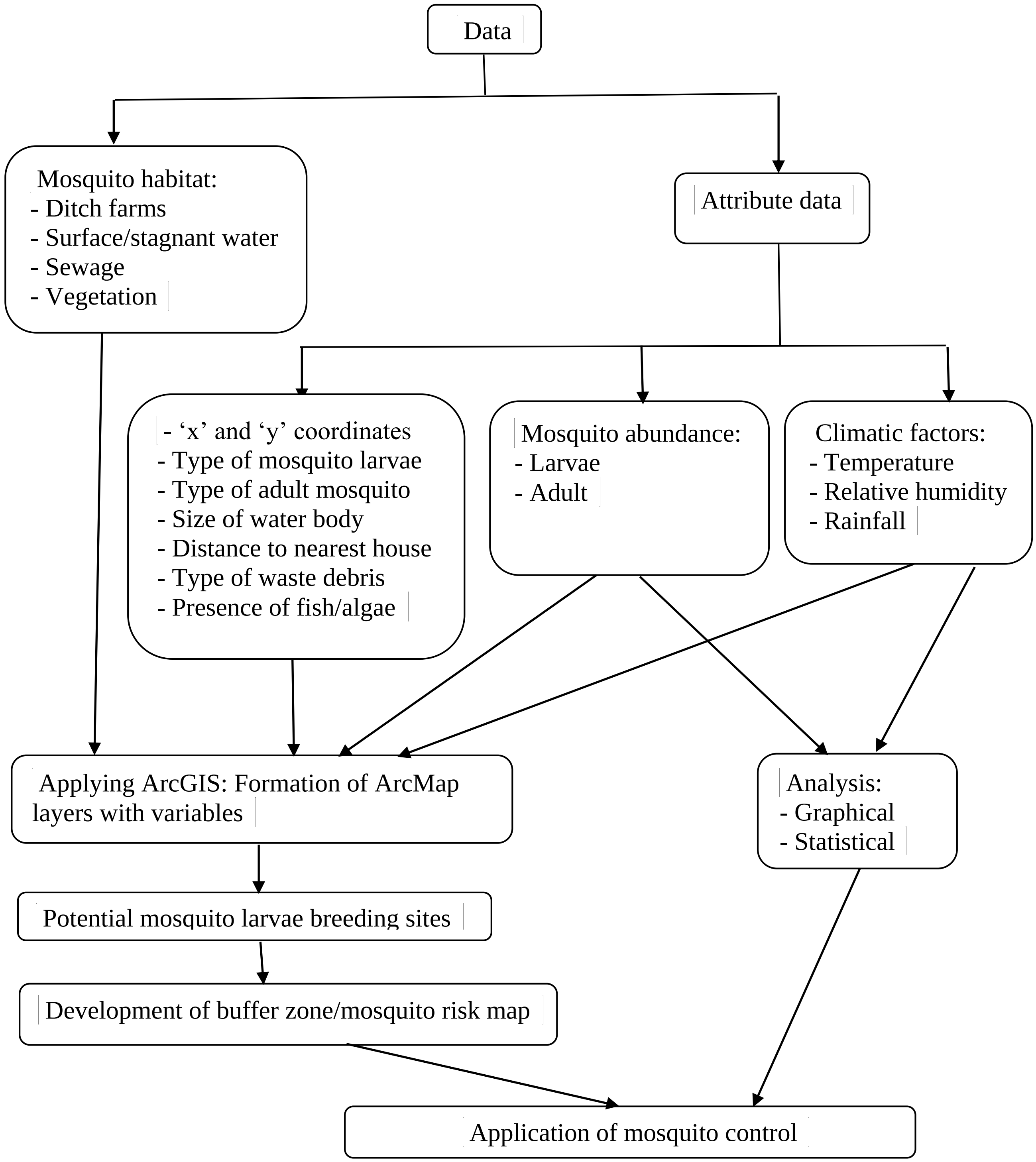

Figure 3. Flowchart demonstrating the main steps of the study procedures

3.6. Spatial and Statistical Data Analysis and Tools

Spatial information and their attributes form the basic part of GIS database. This information was made use of in the development of the maps that can be analyzed visually. The attribute data explained additional information that may not understand by simply looking at the map. Bivariate and multiple regression analyses were performed to identify the relationship between mosquito abundance and climatic factors using IBM® SPSS® version_20.0. Bivariate analysis was made to determine the relationship between mosquito abundance and each climatic factors (temperature, relative humidity and rainfall) while multivariate regression analysis was performed to identify the overall effect of temperature, relative humidity and rainfall in mosquito abundance. A descriptive analysis was also done to determine the trends of mosquito abundance and climatic factors.

The results of bivariate and multivariate analyses were expressed in Pearson correlation value and P-value (significance of association). The values of correlation coefficient showed the linear relationship between mosquito abundance and climatic factors and the P-Value showed the significance of correlation between mosquito abundance and climatic factors.

CHAPTER 4

RESULTS

4.1. Spatial and Seasonal Distribution and Abundance of Larval and Adult Mosquito

The reported number of mosquito larvae and adult mosquito collected for the study period (2014) in Eastern Province, Saudi Arabia are given in Table 2. During the study period, a total of 31041 mosquito larvae and 2036 adult mosquito were collected from January to December 2014.

Of the total 31041 mosquito larvae collected, 20345 (65.54%) were Culex while Aedes and Anopheles account 5641 (18.17%) and 5055 (16.28%) respectively (Table 3). This indicates that Culex mosquito larvae were the most abundant in the study area followed by Aedes while Anopheles was less abundant. Similarly, Culex mosquito larvae were found highly distributed in all sites (in all villages/places), followed by Aedes while Anopheles larvae were found less distributed. Though Culex and Aedes mosquito larvae was collected from all sites, Anopheles mosquito larvae was not collected from Dammam area (Table 4). The monthly distribution and abundance of types of mosquito larvae was displayed in Figure 4.

On the other hand, of the 2036 adult mosquito collected, 1528 (75.05%) were Culex while the remaining, 508 (24.95%) were Anopheles. However, no adult Aedes mosquito was captured throughout the year (Table 3). This didn't reflect non-existence of Aedes mosquito in the area but this was attributed to the limited access of collecting adult mosquitoes from human residence because the residents didn't permit the data collectors to enter their homes to collect adult mosquito. Due to this all adult mosquitoes were captured and collected from rooms of cattle's during morning time (day) using spray killer and cow sheet, but at this specific time (morning) Aedes mosquito rest indoor in human living rooms. As a result, no adult Aedes mosquito was captured for the whole year. In addition, no adult Culex and Anopheles mosquito were collected from certain sites like Buqayq and Al-Sarar throughout the year. But overall, adult Culex was found the most abundant and highly distributed mosquito in the study area, followed by adult Anopheles. Moreover, no adult Anopheles was also collected in Dammam area (Table 4). The monthly distribution and abundance of adult mosquito types was displayed in Figure 5.

Figure 6 shows the location of larvae breeding habitat in each study sites. During the study period, the breeding sites found with mosquito larvae were identified as positive while breeding sites that hadn't mosquito larvae were identified as negative. The x and y coordinates of both positive and negative breeding sites together with other associated environmental characteristics were given in Appendix A.

Development of risk map for the Eastern Province by considering the flying distance of adult mosquito from the studied sites performed. Most adult mosquito species fly within the range of 1-3 km, though some species can travel up to 5 km (WHO 1982). Accordingly, a buffer zone of 1, 3 and 5 km considered as buffer distance or mosquito risk areas Figure 7.

Table 2. Spatial and seasonal distribution of larvae and adult mosquito in Eastern Province, Saudi Arabia in 2014.

Study Area	Month												Total
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Larval													
Abu-Main	163	161	137	89	82	74	32	53	75	75	105	121	1167
Umm As Sahik	206	207	220	198	208	193	83	248	232	171	179	153	2298
Safwa	204	188	129	122	137	145	51	83	117	102	141	158	1577
Al-Awjam	222	271	263	178	192	199	66	181	192	94	140	147	2145
Dammam	100	120	170	80	110	110	20	100	110	60	60	123	1163
Al-Qatif and surrounding area	1027	1898	2651	2082	1055	1260	369	1072	1015	1670	2221	2806	19126
Buqayq	243	206	88	111	75	80	50	50	50	50	60	60	1123
Al-Sarar	297	294	333	275	280	297	0	185	90	141	150	100	2442
Total	2462	3345	3991	3135	2139	2358	671	1972	1881	2363	3056	3668	31041
Adult													
Abu-Main	7	20	21	11	5	4	0	0	0	0	1	59	128
Umm As Sahik	42	65	35	37	17	18	4	25	16	27	24	62	372
Safwa	3	0	0	0	7	9	0	0	0	0	0	9	28
Al-Awjam	63	58	29	23	11	13	7	32	22	10	22	51	341
Dammam	0	0	0	0	0	0	0	0	0	0	6	0	6
Al-Qatif and surrounding area	106	246	295	121	9	0	0	2	0	6	140	236	1161
Buqayq	0	0	0	0	0	0	0	0	0	0	0	0	0
Al-Sarar	0	0	0	0	0	0	0	0	0	0	0	0	0
Total	221	389	380	192	49	44	11	59	38	43	193	417	2036

Table 3. Demonstrates the temporal distribution and abundance of larvae and adult by mosquito type in Eastern Province, Saudi Arabia in 2014.

Stage and type	**Month**												**Total**
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	
Larval													
Culex	1525	1987	2718	2303	1493	1550	410	1505	1483	1680	1547	2144	20345
Aedes	550	896	630	250	278	247	58	210	100	398	1005	1019	5641
Anopheles	387	462	643	582	368	561	203	257	298	285	504	505	5055
Total	2462	3345	3991	3135	2139	2358	671	1972	1881	2363	3056	3668	31041
Adult													
Culex	169	274	273	163	38	44	11	55	36	40	165	260	1528
Aedes	0	0	0	0	0	0	0	0	0	0	0	0	0
Anopheles	52	115	107	29	11	0	0	4	2	3	28	157	508
Total	221	389	380	192	49	44	11	59	38	43	193	417	2036

Table 4. Illustrates the spatial distribution and abundance of larvae and adult by mosquito type in Eastern Province, Saudi Arabia in 2014.

Stage	Area	Culex	Aedes	Anopheles	Total
Larval	Abu-Main	690	235	242	1167
	Umm As Sahik	1275	355	668	2298
	Safwa	770	250	557	1577
	Al-Awjam	1132	343	670	2145
	Dammam	915	248	0	1163
	Al-Qatif and surrounding area	13123	3215	2788	19126
	Buqayq	885	190	48	1123
	Al-Sarar	1555	805	82	2442
	Total	20345	5641	5055	31041
Adult					
	Abu-Main	59	0	69	128
	Umm As-Sahik	291	0	81	372
	Safwa	25	0	3	28
	Al-Awjam	255	0	86	341
	Dammam	6	0	0	6
	Al-Qatif and surrounding area	892	0	269	1161
	Buqayq	0	0	0	0
	Al-Sarar	0	0	0	0
	Total	1528	0	508	2036

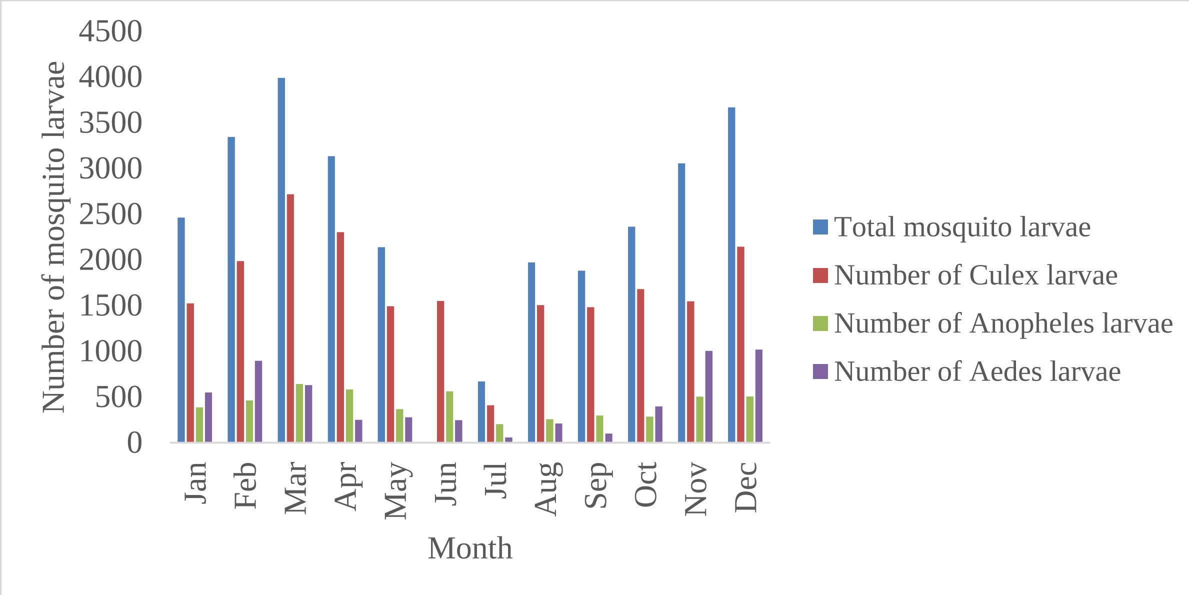

Figure 4. Monthly distribution and abundance of total mosquito larvae, Culex, Anopheles and Aedes larvae in Eastern Province, Saudi Arabia in 2014

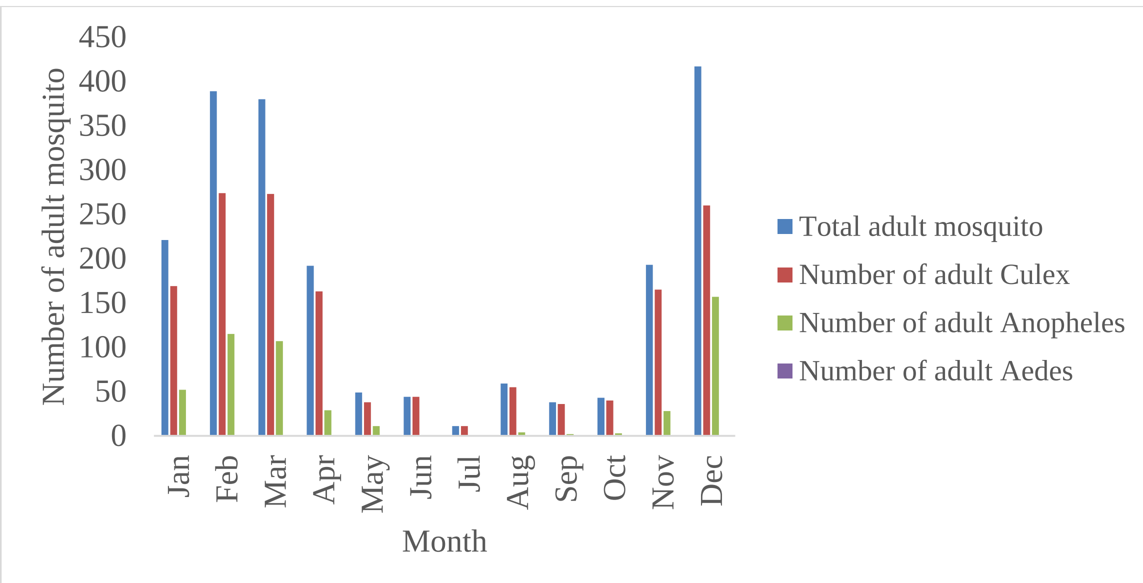

Figure 5. Monthly distribution and abundance of total adult mosquito, Culex, Anopheles and Aedes in Eastern Province, Saudi Arabia in 2014.

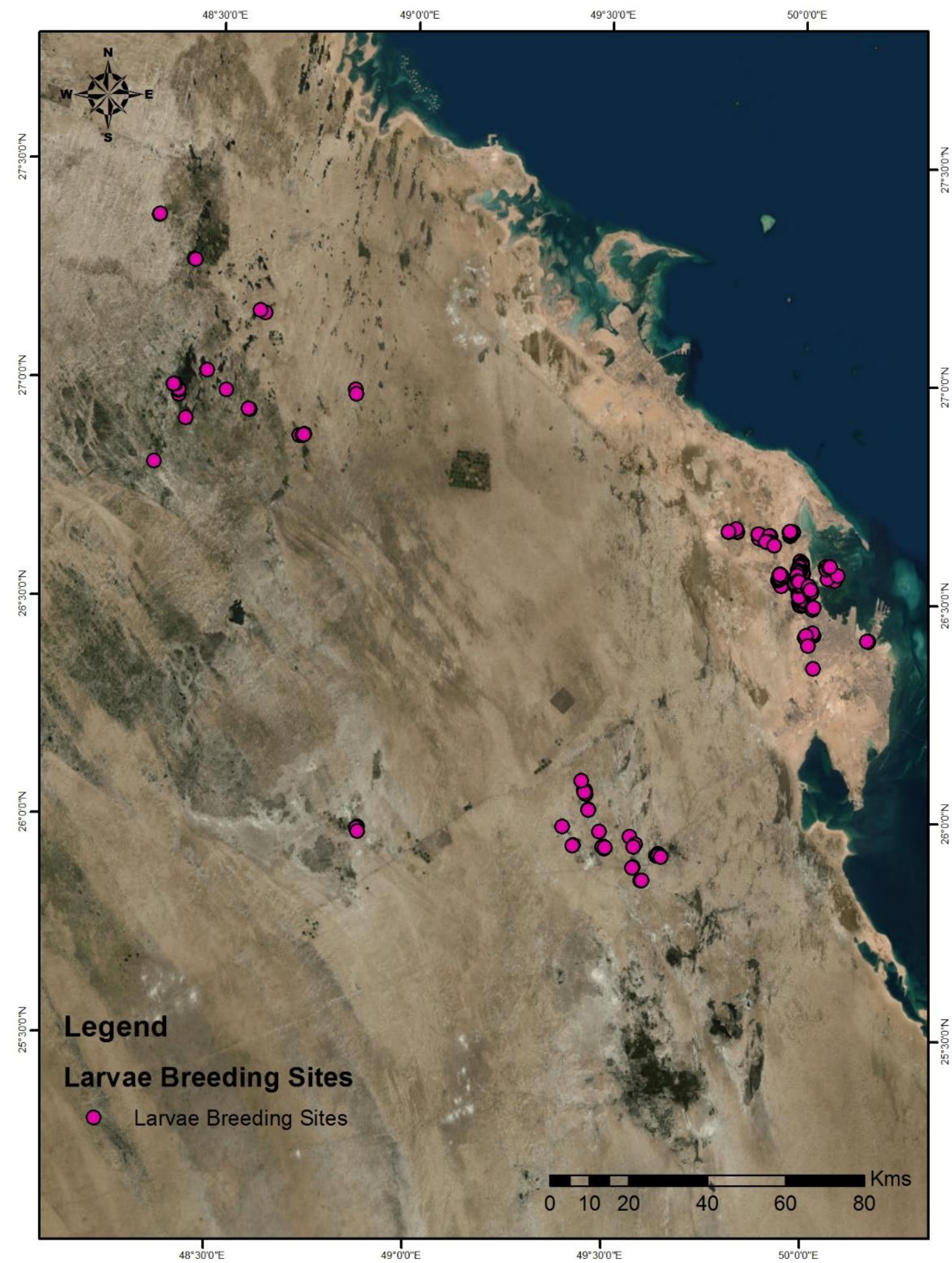

Figure 6. Mosquito breeding sites in Eastern Province, Saudi Arabia, 2014

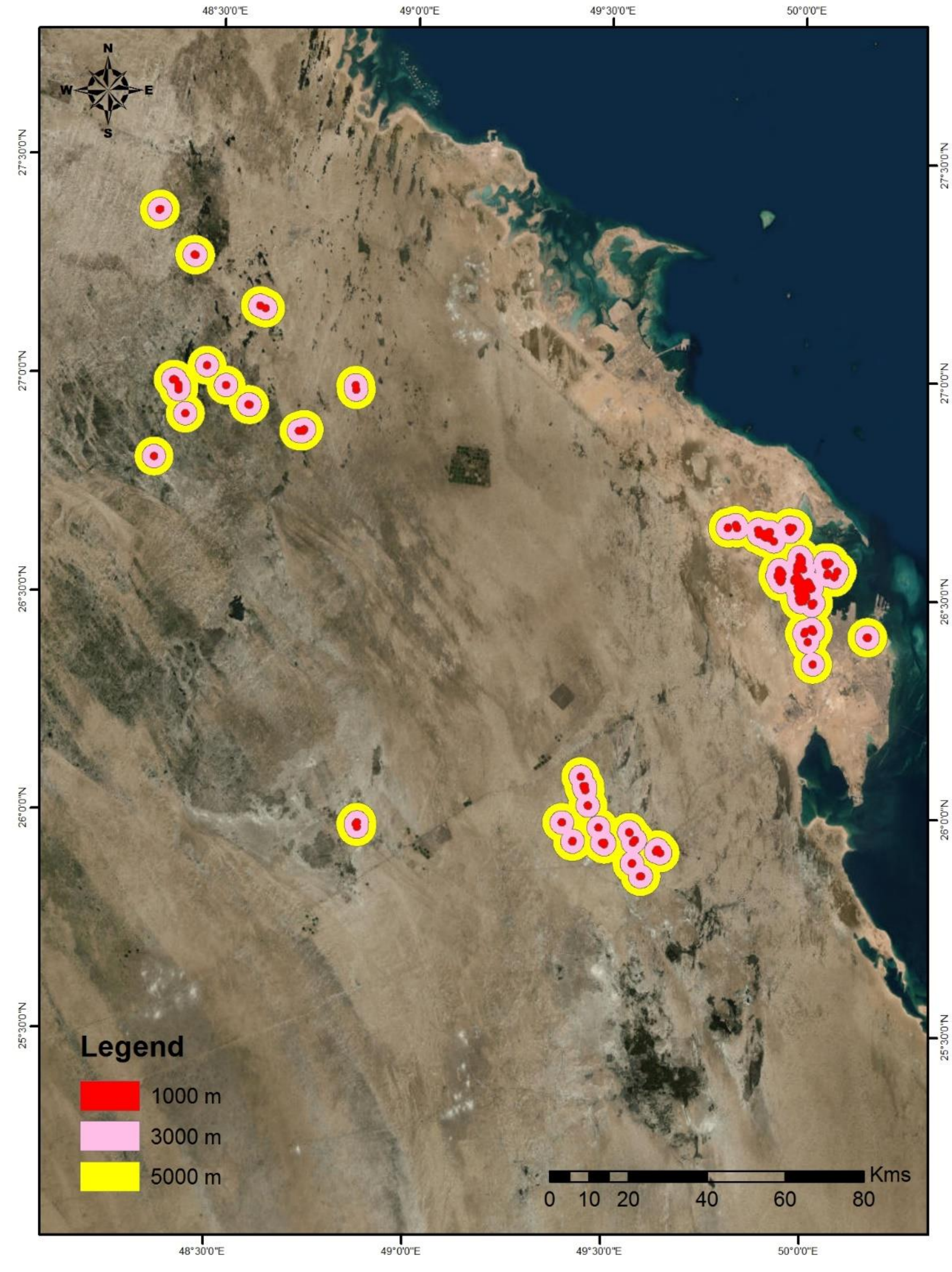

Figure 7. Buffer distance/ mosquito risk area in Eastern Province, Saudi Arabia, 2014

4.1.1. Abu Main Area

4.1.1.1. Spatial abundance of larval and adult mosquito

In this area, 1167 mosquito larvae were collected, and Culex were the most abundant in the area which account 690 (59.13%), followed by 242 (20.74%) Anopheles while the remaining 235 (20.14%) were Aedes (Table 4). 128 adult mosquitoes were also collected from this site and Anopheles was found the most abundant which account 69 (53.91%), followed by Culex 59 (46.09%). However, no adult Aedes mosquito was collected from this area (Table 4).

4.1.1.2. Seasonal abundance of larval and adult mosquito

In general, mosquito larvae were collected throughout the year and the overall sum of mosquito larvae in this area showed that the highest number of mosquito larvae was collected in January and February following the increased precipitation/rainfall during January provided more larval breeding sites in addition to the presence of maximum (69%) relative humidity despite a relatively cool temperature during these months (Fig 8). Strictly speaking, Culex and Anopheles larvae were collected throughout the year but no Aedes larvae was collected from July to September in this site. High number Culex larvae were collected in February following the increased precipitation in January. However, peak numbers of Aedes larvae and Anopheles larvae were collected during the rainy month of January. In general, mosquito larvae were high during January and February in this site (Fig. 9).

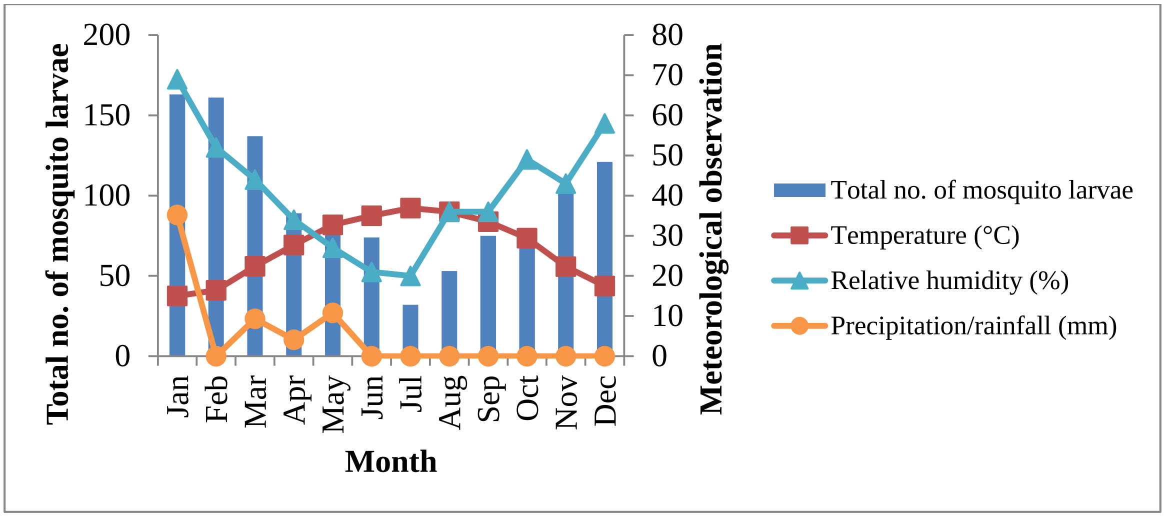

Figure 8. The relationship between climatic factors and total mosquito larvae in Abu Main, Eastern Province, Saudi Arabia in 2014

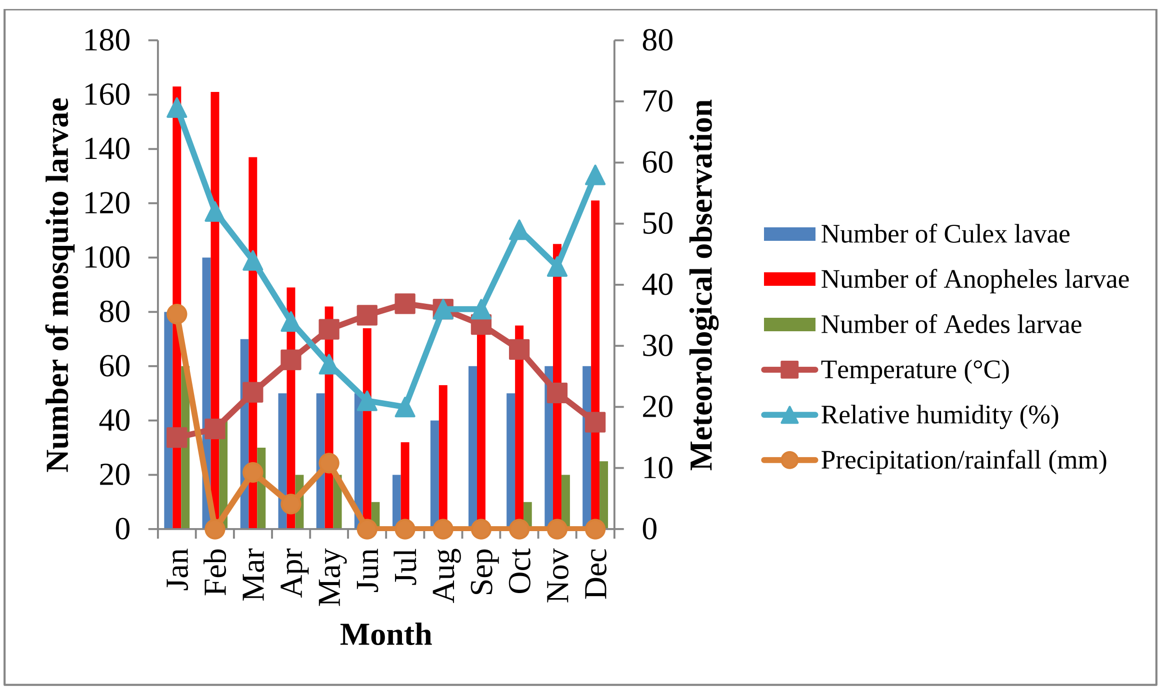

Figure 9. The relationship between climatic factors and Culex, Anopheles and Aedes larvae in Abu Main, Eastern Province, Saudi Arabia in 2014.

Adult mosquito activity was not available throughout the year in this site. In other words, though adult Culex and Anopheles were collected from this area, they were not observed throughout the year, and no adult Aedes mosquito was collected unlike Aedes larvae in this site (Fig. 10). Unlike mosquito larvae, low activity of adult mosquito was observed as a result limited number of adult mosquito was collected depending on the prevailing climatic conditions. A relatively faire activity of adult mosquito was observed in December, when the temperature was 17.5 °C and relative humidity of 58% and no mosquito activity was collected from July to October.

Limited activity of adult mosquito were observed during the rainy months of January, March, April and May and started to decrease during the onset of the dry season in June and no adult mosquito were collected from July to October, but started to rebuild when the temperature decreased to 17.5 °C in December (Fig. 10). The mosquito control measures which were taken following the increased precipitation/rainfall were the main reasons for the limited activity of adult mosquito from January to May in the area. Similarly, the activity of adult mosquito by type was also low as displayed in Figure 11.

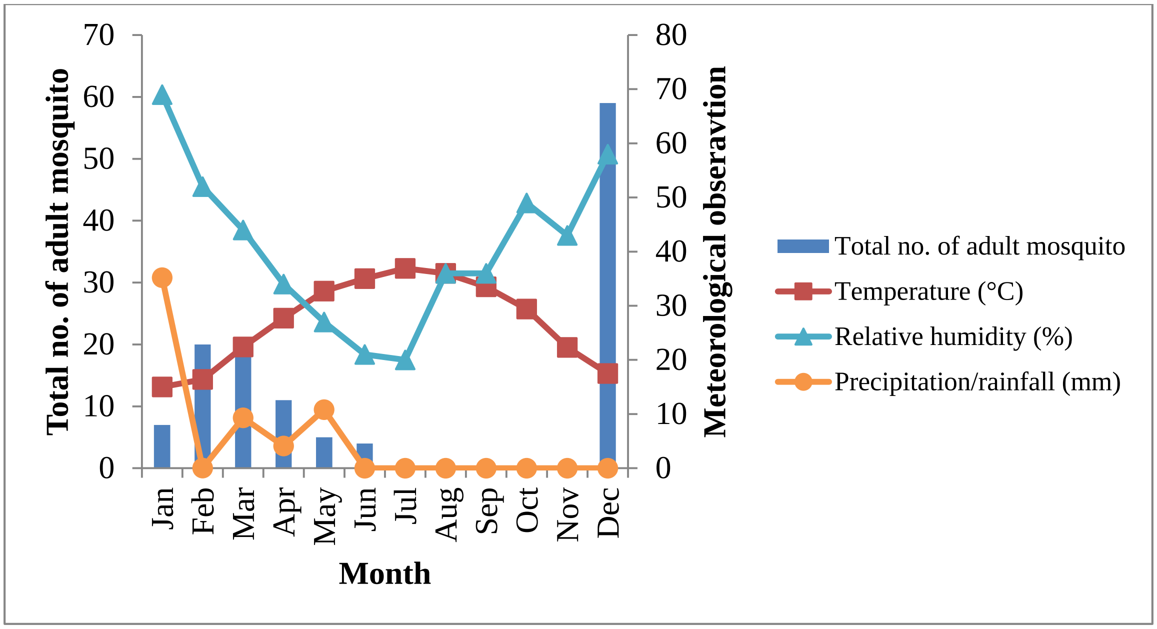

Figure 10. The relationship between climatic factors and total Adult mosquito in Abu Main, Eastern Province, Saudi Arabia in 2014.

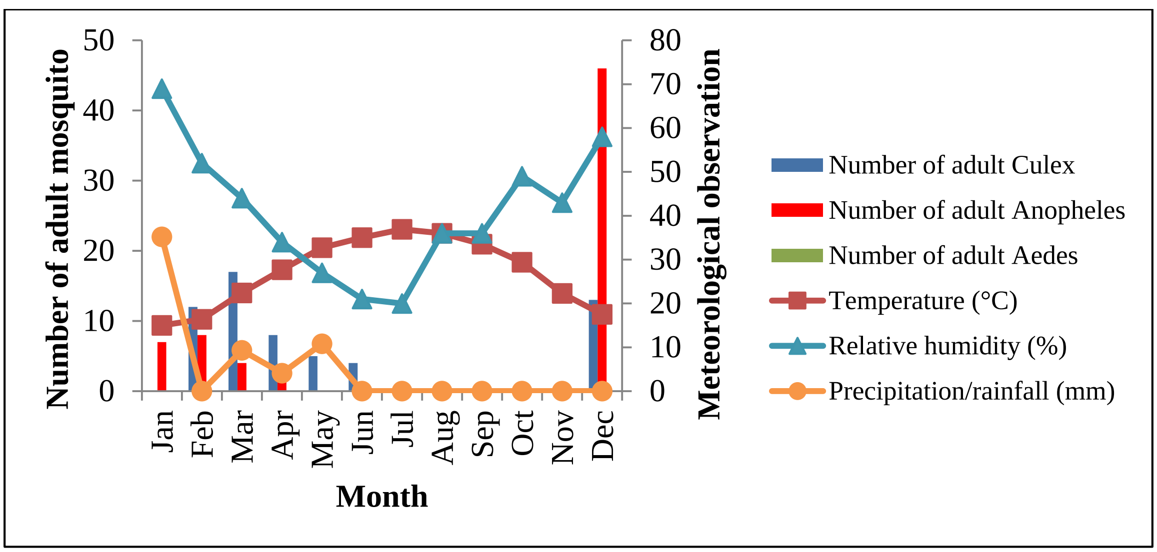

Figure 11. The relationship between climatic and adult Culex, Anopheles, and Aedes mosquito in Abu Main, Eastern Province, Saudi Arabia in 2014.

4.1.2. Umm As Sahik Area

4.1.2.1. Spatial abundance of larval and adult mosquito

In this site, 2298 mosquito larvae were collected and Culex larvae were found the most abundant where 1275 (55.48%) were collected, followed by Anopheles 668 (29.07%) while the remaining 355 (15.45%) were Aedes larvae (Table 4). Of the total 372 adult mosquito collected, 291 (78.23%) were culex and the rest 81 (21.77%) were Anopheles. Similar to other sites, no Aedes adult was reported from this area (Table 4).

4.1.2.2. Seasonal abundance of larval and adult mosquito

In this site, Culex, Aedes and Anopheles larvae were observed throughout the year. The highest number of larvae was collected during the month of August when the temperature was 36 ^{o}C and relative humidity was 36%, and then during September when the temperature was 33. 5 ^{o}C and relative humidity was 36% but in general, a large number of mosquito larvae were collected from January to May following the increased precipitation/rainfall during these months (Fig. 12).

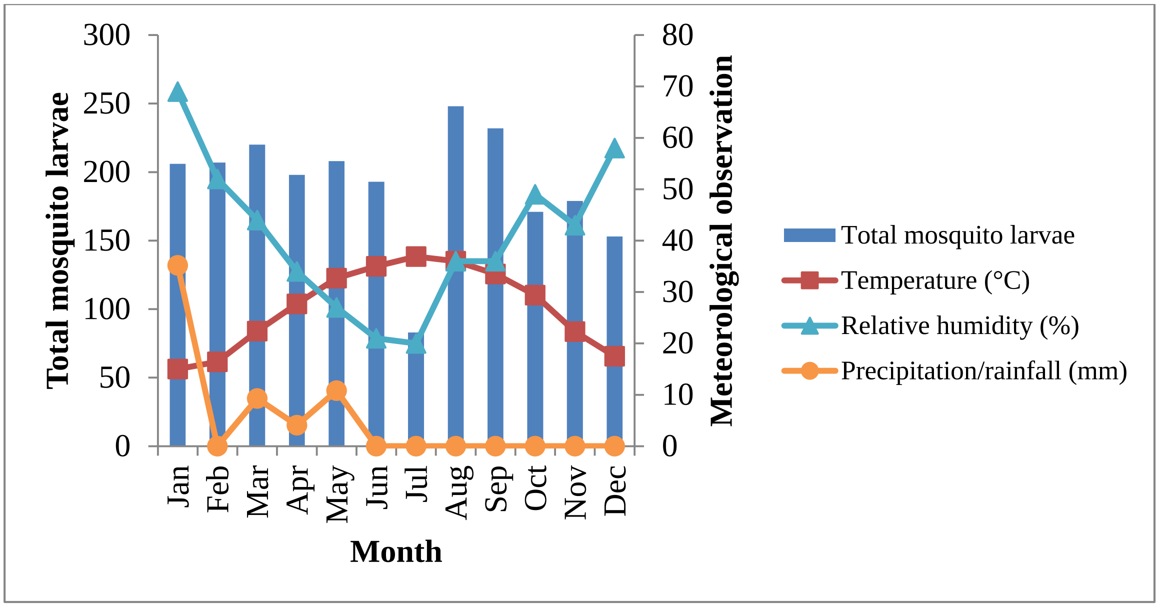

Figure 12. The relationship between climatic factors and total mosquito larvae in Umm As Sahik, Eastern Province, Saudi Arabia in 2014.

Similar to the trend of overall mosquito larvae, high number of Culex larvae was also collected during the dry season in August and September. However, a moderate number of Anopheles and Aedes larvae were collected in April and May, and March respectively following the rainy season during January to May (Fig. 13).

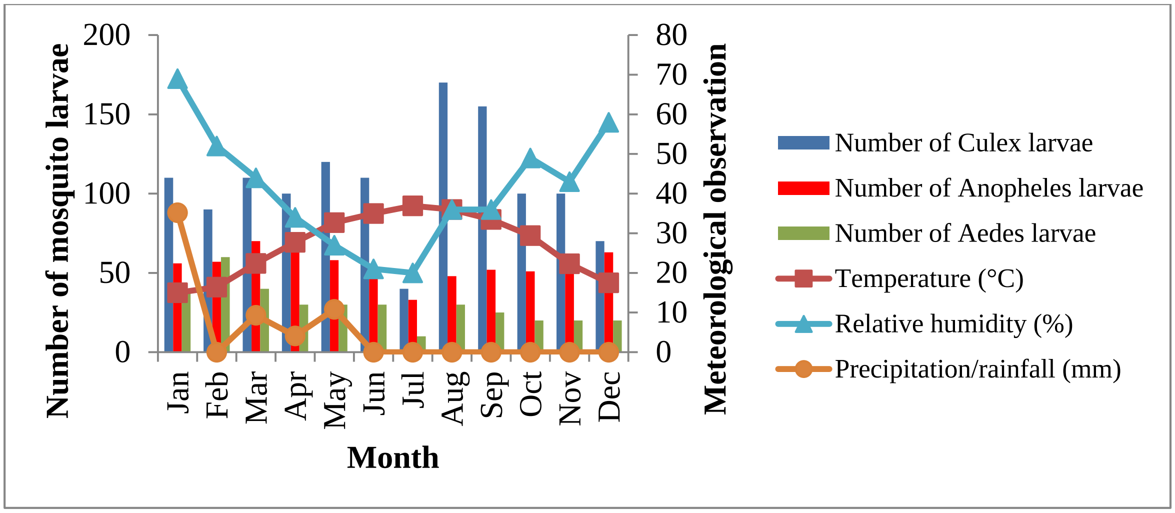

Figure 13. The relationship between climatic factors and Culex, Anopheles and Aedes larvae in Umm As Sahik, Eastern Province, Saudi Arabia in 2014.

Based on the overall data, adult mosquito activity was observed throughout the year but at different numbers depending on the existing climatic conditions. Moderate number of adult mosquito was collected during February, when the temperature was 16.4 ^{o}C and relative humidity was 52%, and it started to decrease until reached a minimum in July, when the temperature was at maximum (36.9 ^{o}C) and relative humidity was at minimum (20%). The increased precipitation during January created more larval breeding sites and moderate activity was attained in February. The number of mosquito reached at minimum with the start of the hottest month of July (Fig. 14).

Though the activity of adult Culex was observed throughout the year, it was at different number depending on the existing climatic conditions. On the other hand, a very few adult Anopheles were collected from January to April following the rain season and then no activity of adult Anopheles was observed from May to September, when the temperature increased and relative humidity decreased, and started to rebuild with the decrease in temperature and increase in relative humidity (Fig. 15).

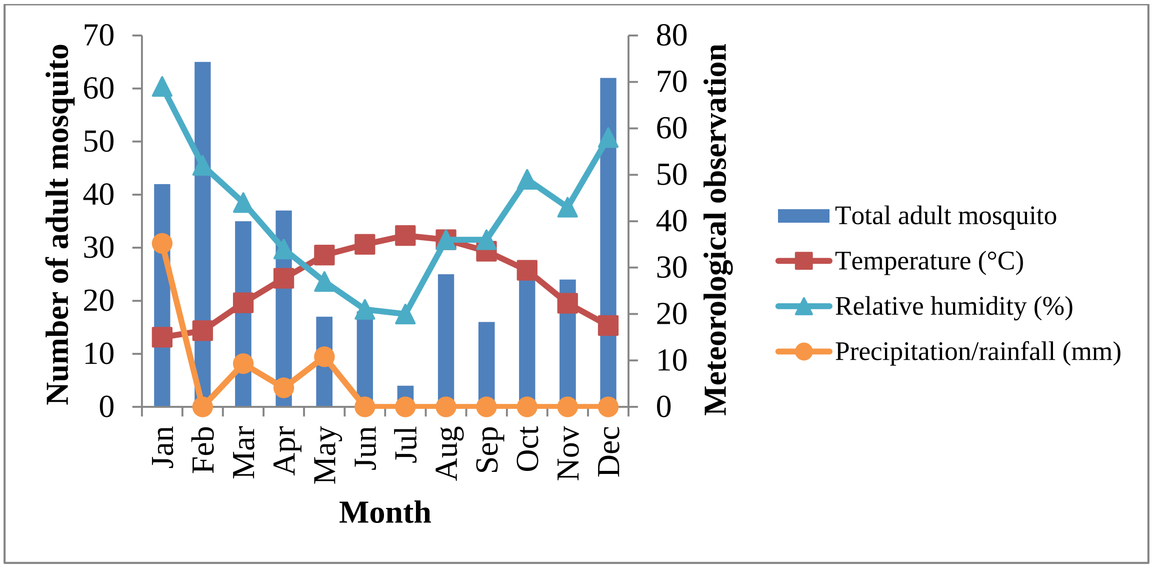

Figure 14. The relationship between climatic factors and total adult mosquito in Umm As Sahik, Eastern Province, Saudi Arabia in 2014.

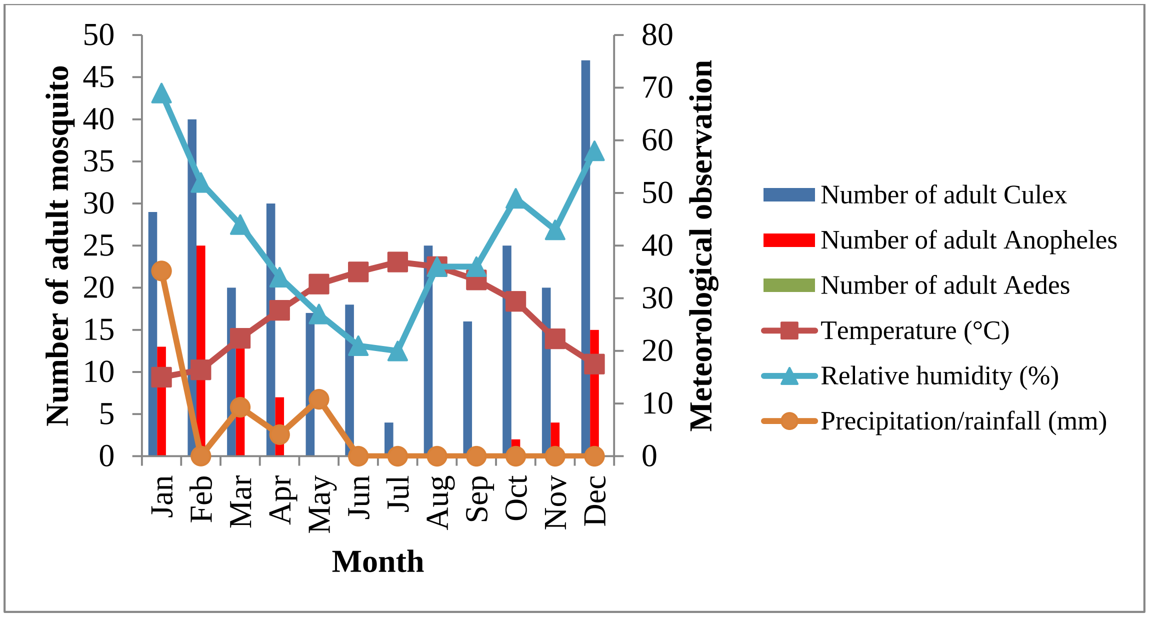

Figure 15. The relationship between climatic factors and adult Culex, Anopheles and Aedes in Umm As Sahik, Eastern Province, Saudi Arabia in 2014.

4.1.3. Safwa Area

5.1.3.1. Spatial abundance of larval and adult mosquito

Out of 1577 mosquito larvae collected in this site, 770 (48.83% were Culex larvae which were the most abundant, followed by 557 (35.32%) Anopheles and the rest 250 (15.85%) were Aedes larvae. However, only 28 adult mosquitoes were collected from this area, of these 25 are adult Culex while the remaining 3 are adult Anopheles, and similar to the previous sites no adult Aedes was also reported from this area (Table 4).

5.1.3.2. Seasonal abundance of larval and adult mosquito

The overall mosquito larvae collected indicates the availability of mosquito larvae throughout the year in this area (Fig. 16). However, Aedes larvae were not observed from

July to September, when the temperature was high (Fig. 17). High number of mosquito larvae were observed in January, when the temperature was 15 °C, relative humidity 69% and high rainfall, and minimum number was attained in July, when the temperature was high (36.9 °C) and relative humidity was minimum (20%) (Fig. 16). The seasonal abundance of mosquito larvae by type was displayed in Figure 14. On the other hand, a very limited activity of adult mosquito was observed and no adult mosquito was collected in most of the months in this site (Table 2).

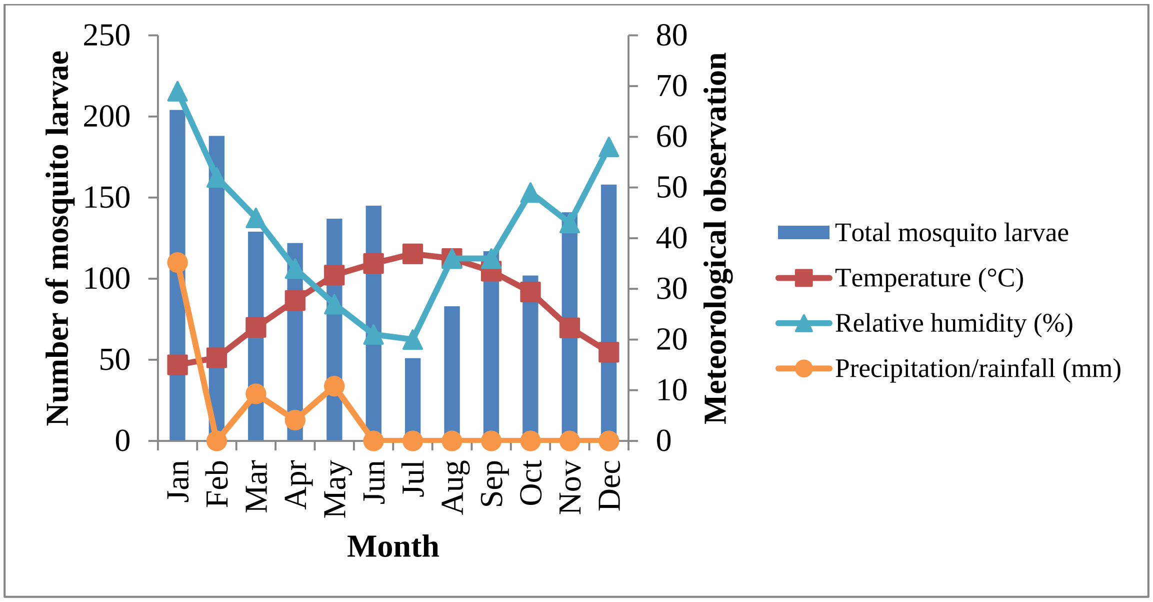

Figure 16. The relationship between climatic factors and total mosquito larvae in Safwa, Eastern Province, Saudi Arabia in 2014.

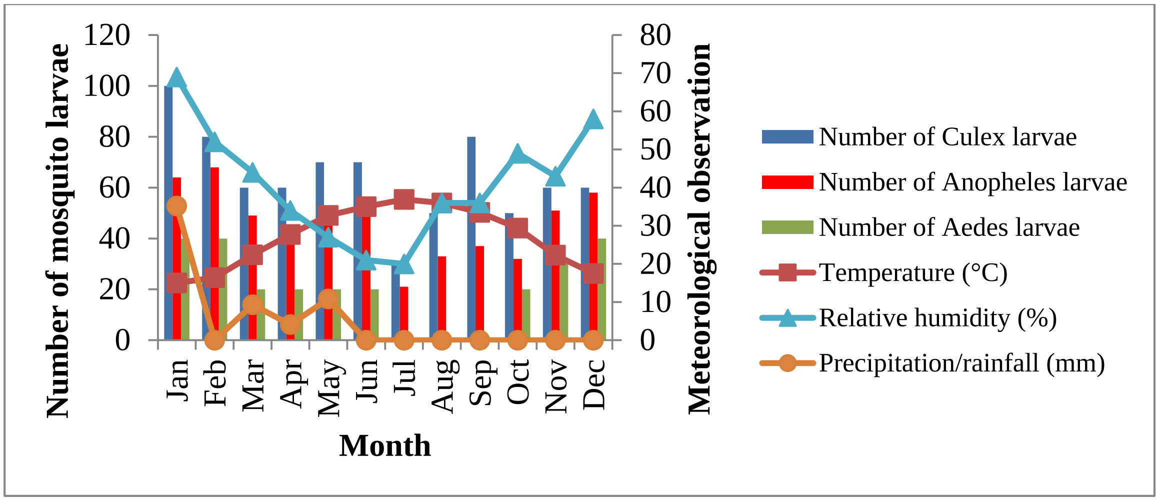

Figure 17. The relationship between climatic factors and Culex, Anopheles and Aedes larvae in Safwa, Eastern Province, Saudi Arabia in 2014.

4.1.4. Al- Awjam Area

4.1.4.1. Spatial abundance of larval and adult mosquito

In this site, 2145 mosquito larvae were collected and Culex larvae were the most abundant where 1132 (52.77%) were collected, followed by Anopheles 670 (31.24%) and Aedes 343 (15.99%). On the other hand, out of 341 adult mosquito collected, 255 (74.78%) of them were adult Culex which was the most prevalent in the site whereas the rest 86 (25.22%) were adult Anopheles (Table 4).

4.1.4.2. Seasonal abundance of larval and adult mosquito.

In general, mosquito larvae were collected throughout the year (Fig. 18). However, only Culex larvae and Anopheles larvae were available throughout the year while Aedes larvae were not collected during the month of October in this area (Fig. 19). The increase in precipitation during January to May provided more larval breeding sites as a result a relatively high number of mosquito larvae were collected from January to June but low number of mosquito larvae was collected in July, when the temperature was at maximum (36.9 ^{o}C) (Fig. 18) and specifically, a similar trend was observed with Culex, Anopheles and Aedes mosquito larvae (Fig. 19).

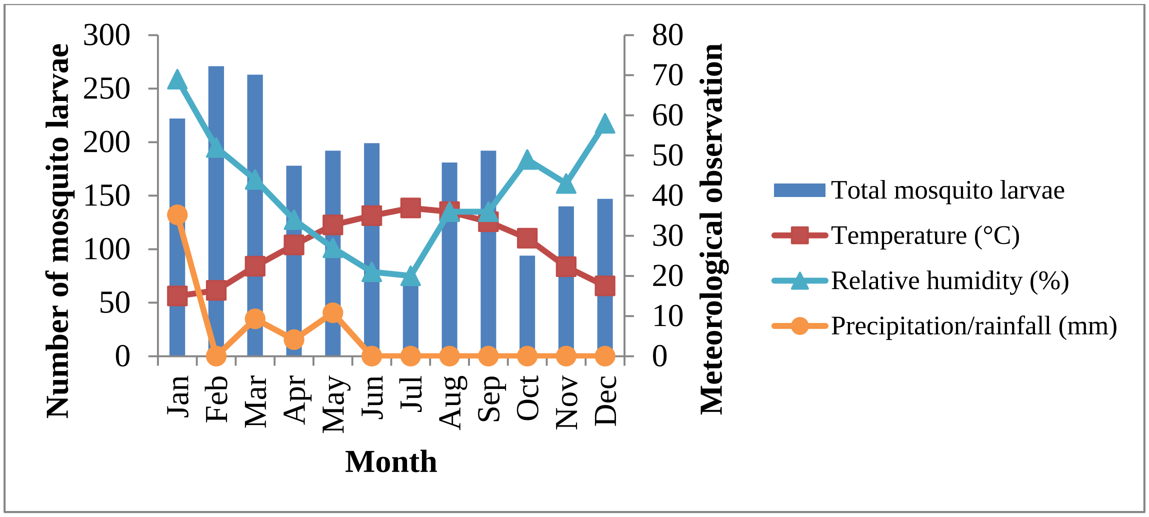

Figure 18. The relationship between climatic factors and total mosquito larvae in Al-Awjam, Eastern Province, Saudi Arabia in 2014.

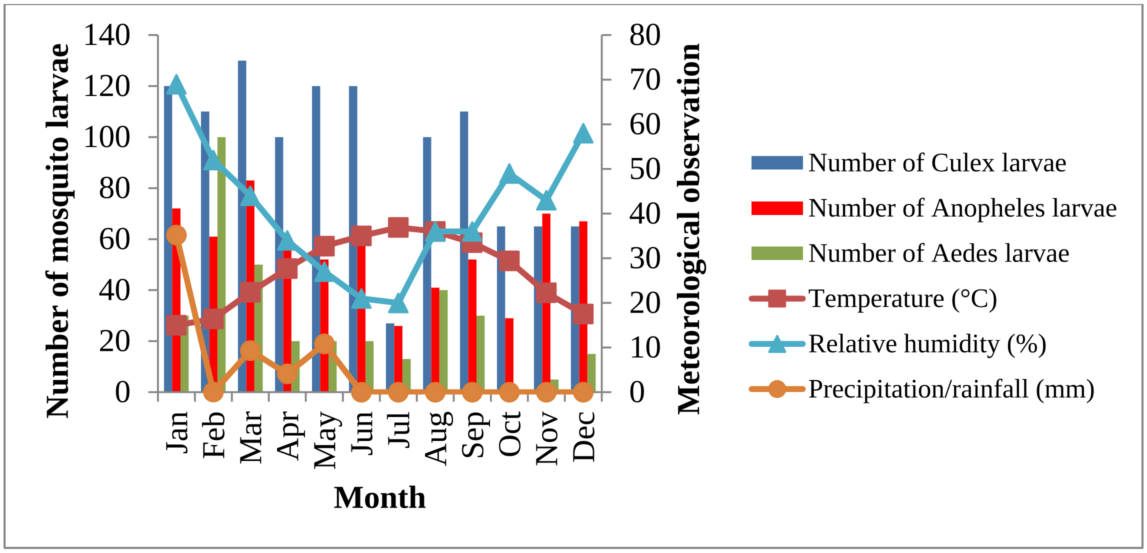

Figure 19. The relationship between climatic factors and Culex, Anopheles and Aedes larvae in Al-Awjam, Eastern Province, Saudi Arabia in 2014.

In this site, activity of adult mosquito was available throughout the year and fair number of adult mosquito were collected during winter season (December, January and February) which is characterized by the presence of a relatively cool temperature, optimum relative humidity and increased precipitation provided more larval breeding sites that led to the increased activity of adult mosquito. However, minimum number of adult mosquito was recorded during the hottest month of July, when the temperature was at maximum (36.9 ºC) and RH was 20% (Fig 20).

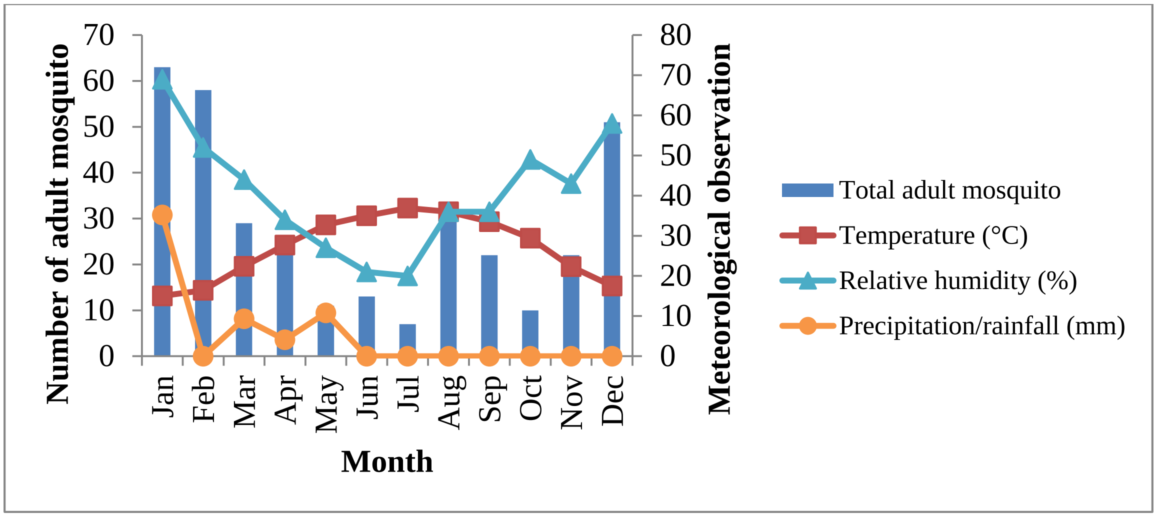

Figure 20. The relationship between climatic factors and total adult mosquito in Al-Awjam, Eastern Province, Saudi Arabia in 2014.

Specifically speaking, only adult Culex was collected in all months while adult Anopheles was not observed in June, July and October. Similar to the overall adult mosquito activity, fair number of adult Culex and Anopheles was observed during winter season as a result of cool temperature, conducive relative humidity and increased precipitation which created more larval breeding sites (Fig. 21).

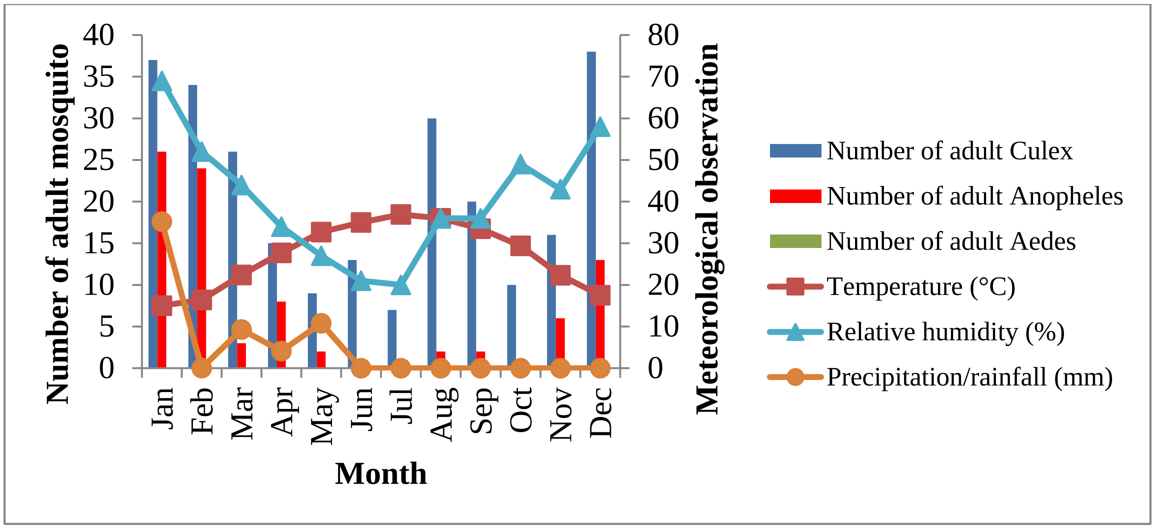

Figure 21. The relationship between climatic factors and adult Culex, Anopheles and Aedes in Al-Awjam, Eastern Province, Saudi Arabia in 2014.

4.1.5. Dammam Area

4.1.5.1. Spatial abundance of larval and adult mosquito

A total of 1163 mosquito larvae were collected in this site and Culex larvae were the most prevalent where 915 (78.68%) were collected, followed by Aedes 248 (21.32%) and no Anopheles larvae was reported from this area. Unlike to mosquito larvae, a very few number of adult mosquito were collected and all of them were adult Culex but no adult Aedes and Anopheles were observed in this site (Table 4).

4.1.5.2. Seasonal abundance of larval and adult mosquito

In this site, fair and minimum number of mosquito larvae was collected in March and July respectively depending on the prevailing climatic conditions. Overall, high mosquito larvae were observed during winter and spring seasons due to the existed climatic conditions (Fig.

22). Similar trend of abundance was also observed by Culex and Aedes mosquito larvae in this site as shown below in Figure 23.

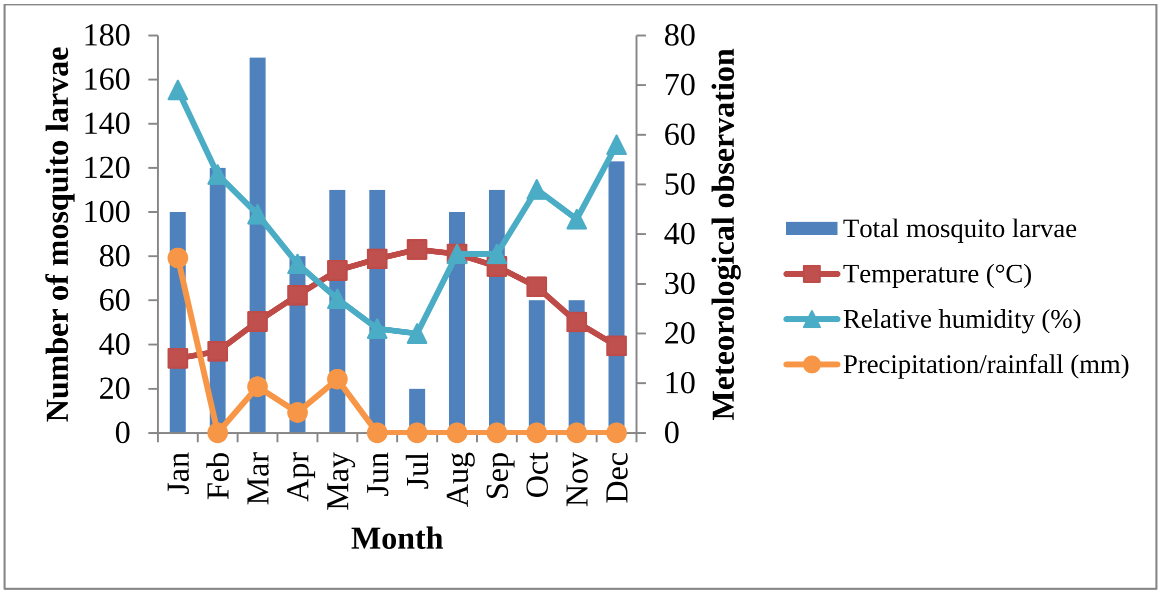

Figure 22. The relationship between climatic factors and total mosquito larvae in Dammam, area, Eastern Province, Saudi Arabia in 2014.

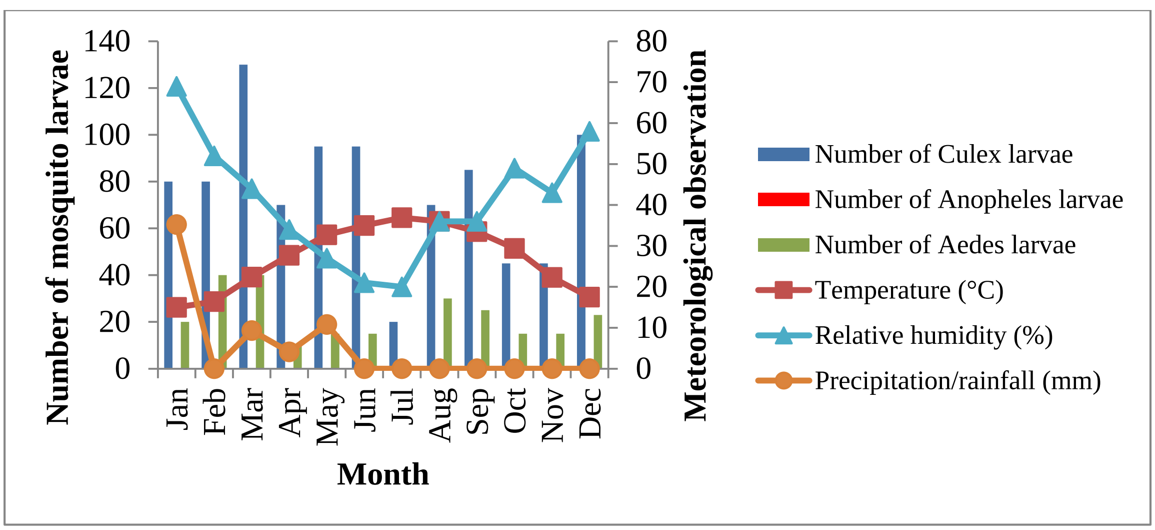

Figure 23. The relationship between climatic factors and Culex, Anopheles and Aedes larvae in Dammam area, Eastern Province, Saudi Arabia in 2014.

4.1.6. Al-Qatif and its Surrounding Area

4.1.6.1. Spatial abundance of larval and adult mosquito

This site includes places like Al-Awamiyah, Al-Qudaih, Al-Bahari, At Tawbi, Al-Khuwaildiyah, Al-Hilah, Al-Jarudiyah, Umm Al Hamam, Al-Mallahah, Al-Jesh, Saihat, Al-Qatif, Anak, and Tarout areas (Darin, Al-Rabieya, Senabis and Fariqel Atrash), and a total 19126 mosquito larvae were collected and Culex larvae were the most abundant where 13123 (68.61%) were collected, followed by 3215 (16.81%) Aedes and the remaining 2788 (14.58%) were Anopheles larvae. On the other hand, out of 1161 adult mosquito collected, 892 (76.83%) were adult Culex while the rest 269 (23.17%) were adult Anopheles (Table 4). Similar to Culex larvae, adult Culex were also the most prevalent in this site.

4.1.6.2. Seasonal abundance of larval and adult mosquito

In this site, mosquito larvae were observed throughout the year and high number of mosquito larvae was collected during December, when the temperature was 17.5 ^{o}C and relative humidity was 58%. In general, high number of mosquito larvae was observed during spring season (March, April and March), followed by winter season (December, January and February) due to the existing climatic conditions (Fig. 24). Strictly speaking, high number of Culex larvae was observed in March, when the temperature was 22.4 ^{o}C and relative humidity was 44%. Increased rainfall during March and in January also provided more larvae breeding sites, which led to attainment of high number of Culex larvae in March. However, more Aedes larvae was collected in December similar to trend of overall mosquito larvae while quite number of Anopheles were seen in November, when 22.3 ^{o}C and RH was 43% (Fig. 25).

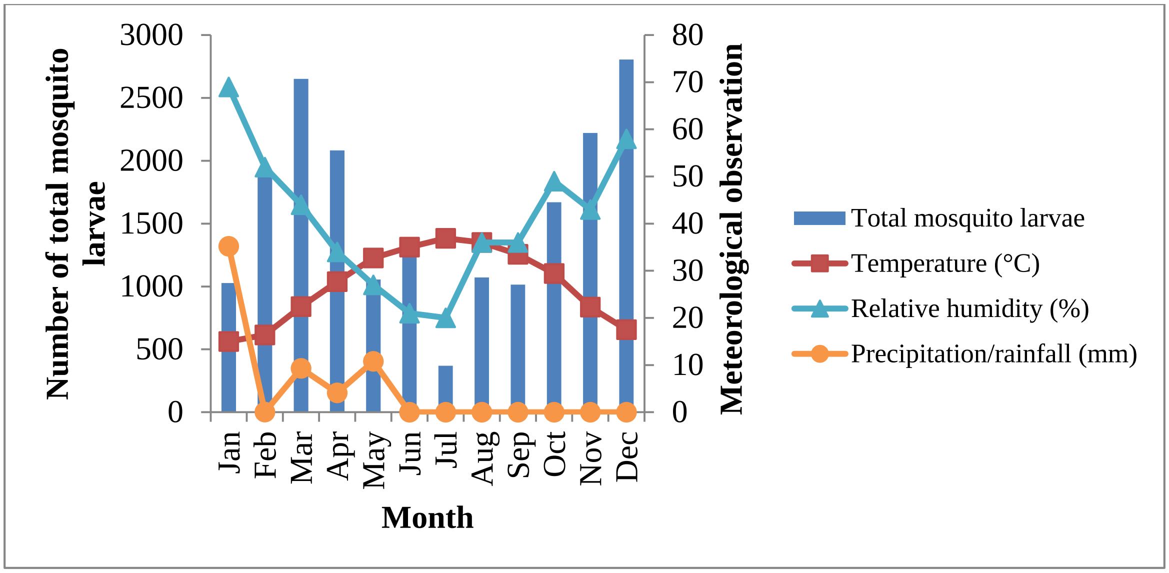

Figure 24. The relationship between climatic factors and total mosquito larvae in Al-Qatif and surrounding area, Eastern Province, Saudi Arabia in 2014.

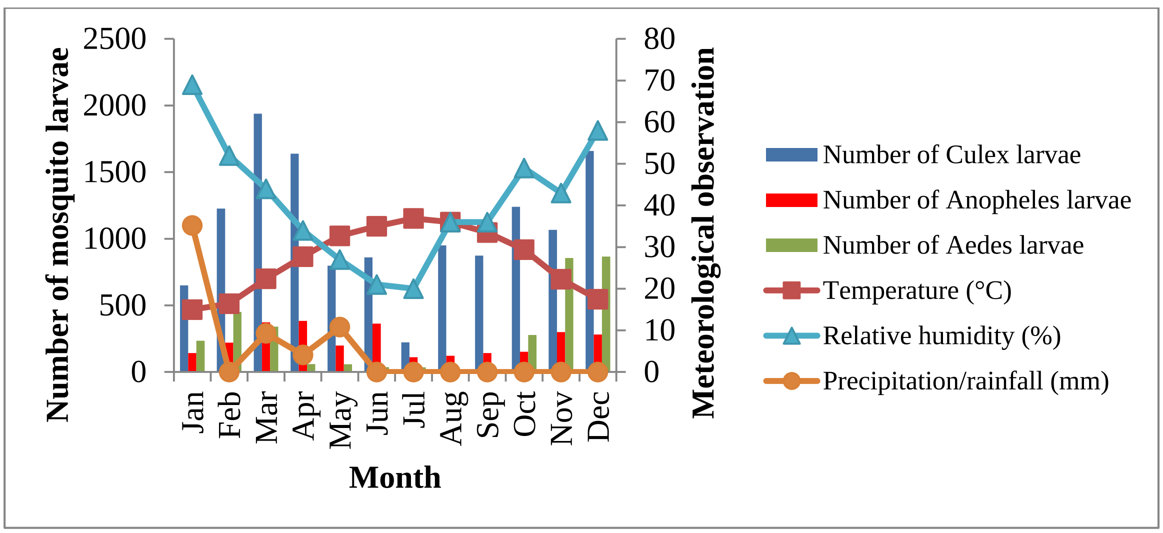

Figure 25. The relationship between climatic factors and Culex, Anopheles and Aedes larvae in Al-Qatif and surrounding area, Eastern Province, Saudi Arabia in 2014.

Adult mosquito was not available throughout the year but in general, a reasonable activity of adult mosquito was observed during winter season (December, January and February), when the temperature was cool and quite rainy and a peak activity of adult mosquito was observed in March, when the temperature was 22.4 °C and relative humidity was 44%. Increased rainfall during March and in January also provided more larvae breeding sites, which led to attainment of high number of adult mosquito in March. On the other hand, very limited or no activity of adult mosquito was observed from May to October (Fig. 26). Similar trend was also observed by adult Culex and Anopheles as illustrated in Figure 27.

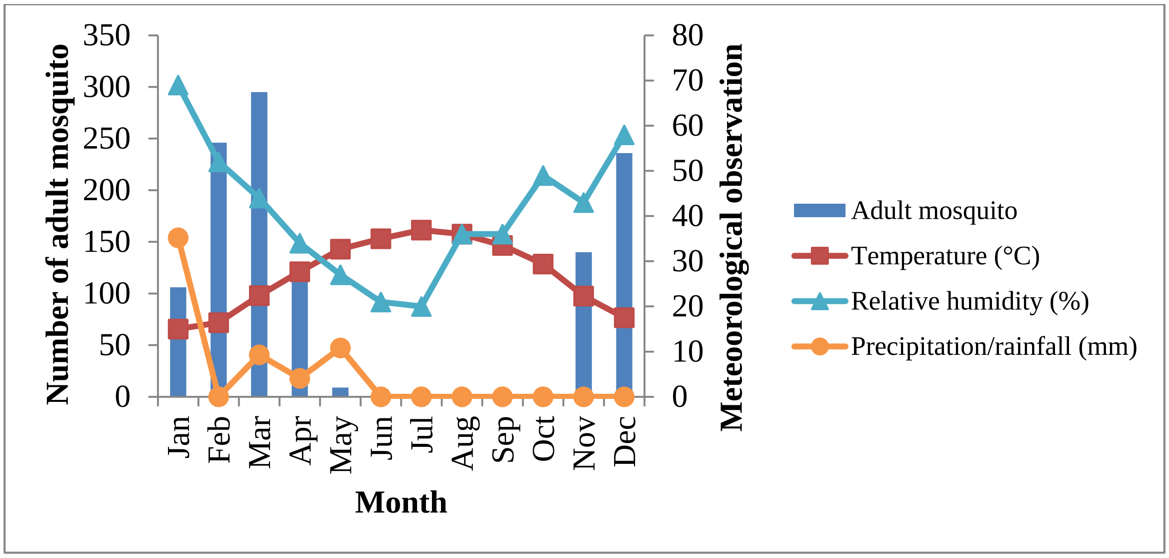

Figure 26. The relationship between climatic factors and total adult mosquito in Al-Qatif and surrounding area, Eastern Province, Saudi Arabia in 2014.

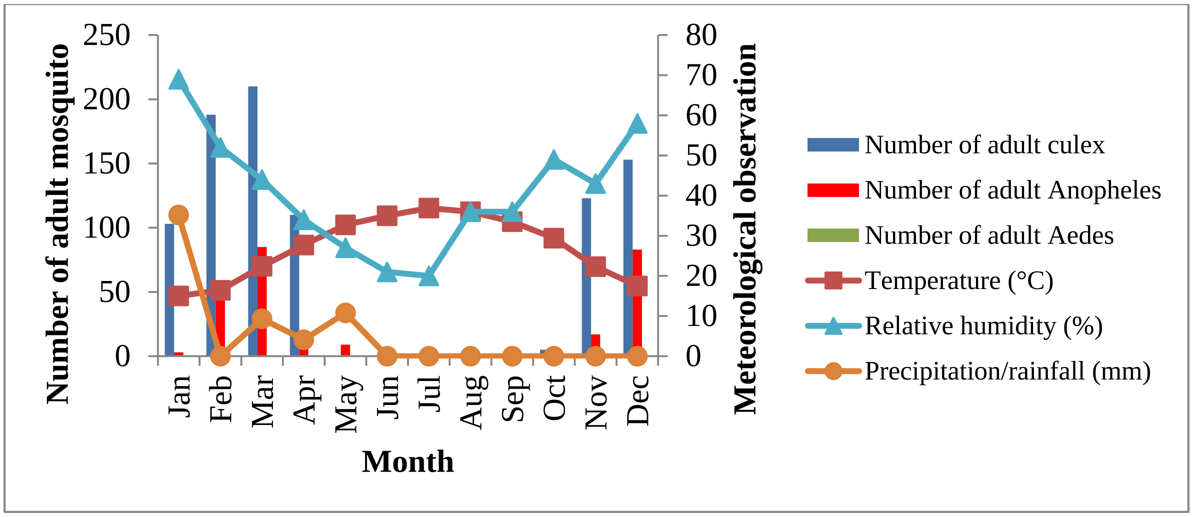

Figure 27. The relationship between climatic factors and adult Culex, Anopheles and Aedes in Al-Qatif and surrounding area, Eastern Province, Saudi Arabia in 2014.

4.1.7. Buqayq Area

4.1.7.1. Spatial abundance of larval and adult mosquito

In this site, a total of 1123 mosquito larvae were collected and Culex larvae were the most prevalent which account 885 (78.81%), followed by 190 (16.92%) and the reaming 48 (4.27%) were Anopheles larvae. However, no adult mosquito was collected throughout the year (Table 4).

4.1.7.2. Seasonal abundance of larval and adult mosquito.

Overall, mosquito larvae were collected throughout the year, but at different numbers. In this site, a fair number of mosquito larvae were collected in January and it started to decline dramatically until reached minimum in July where the temperature was maximum (36.9 ^{o}C)and RH was minimum (20%) (Fig. 28). The reason for the increased number of mosquito larvae was attributed to prevailing climatic conditions during January.

Specifically speaking, no Anopheles and Aedes larvae were collected from May to December and July to December respectfully but Culex larvae were observed throughout the year (Fig. 29). Despite the presence of mosquito larvae, no adult mosquito activity was available the whole year.

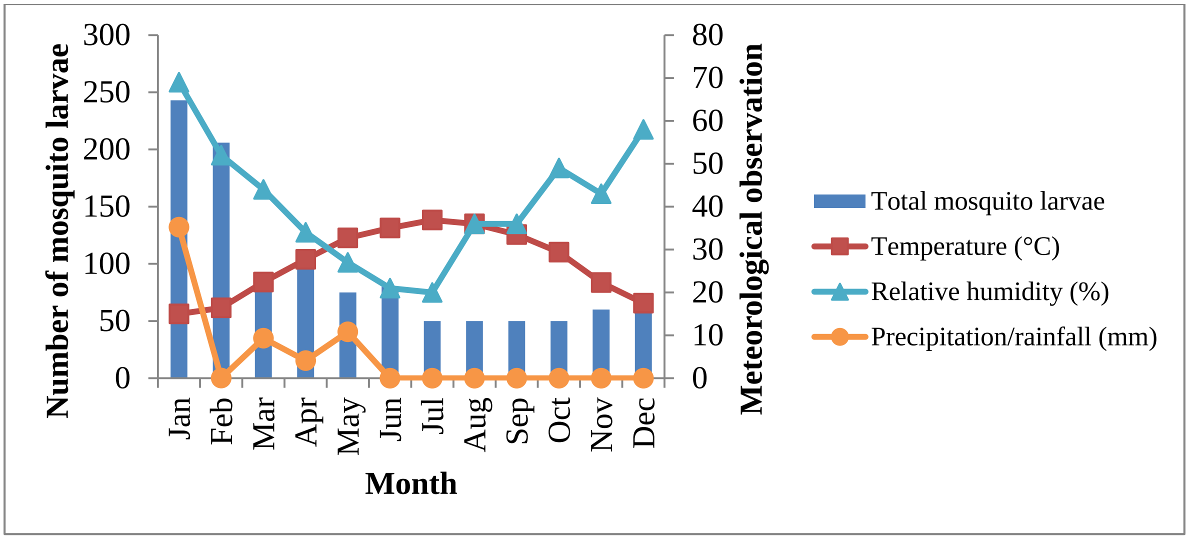

Figure 28. The relationship between climatic factors and total mosquito larvae in Buqayq, Eastern Province, Saudi Arabia in 2014.

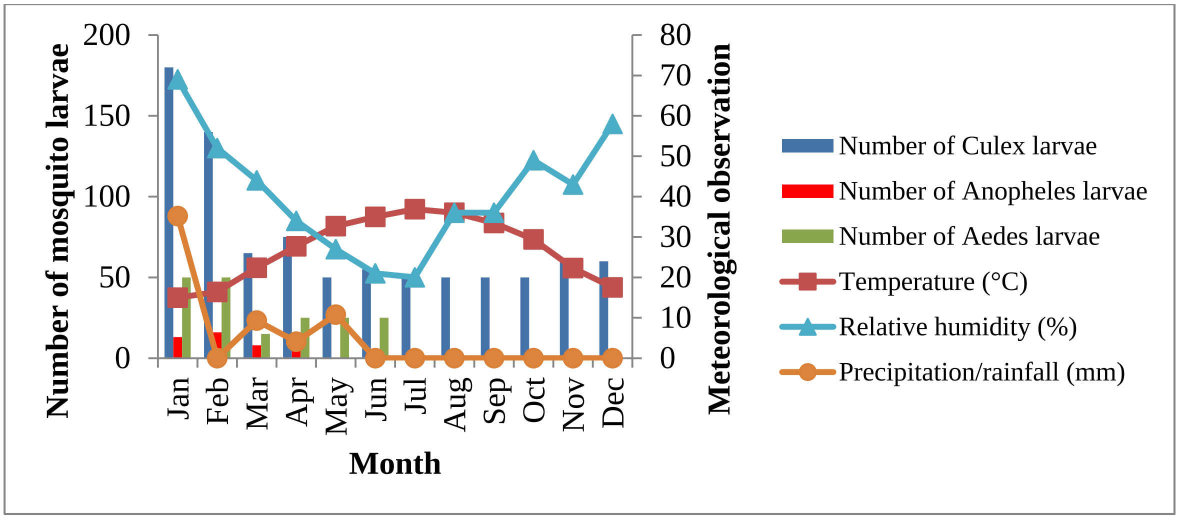

Figure 29. The relationship between climatic factors and Culex, Anopheles and Aedes larvae in Buqayq, Eastern Province, Saudi Arabia in 2014.

4.1.8. Al Sarar Area

4.1.8.1. Spatial abundance of larval and adult mosquito

In this site, 2442 mosquito larvae were collected and Culex larvae were the most prevalent which account 1555 (63.68%), followed by 805 (32.96%) Aedes and the rest 82 (3.36%) were Anopheles larvae. However, adult mosquito was not collected from this area (Table 4).

4.1.8.2. Seasonal abundance of larval and adult mosquito

In this site, mosquito larvae were not collected throughout the year. The highest number of mosquito larvae was collected in March while in July no mosquito larvae were collected. The increased rainfall in January provided more larvae breeding sites and a peak of mosquito larvae was attained in March while the hottest temperature (36.9 ^{o}C) and low relative humidity (20%) in July led to the unavailability of mosquito larvae. In general, large number of mosquito larvae were collected during spring season (March, April and May), followed by winter season (December, January and February) depending on the existing climatic condition (Fig. 30).

Though Culex, Aedes and Anopheles larvae were collected from this area, none of them were available in July. In addition, Anopheles larvae were not collected from April to December, except in June (Fig. 31). The reason is due to the changes in existed climatic conditions as the increase and decrease in temperature and relative humidity especially from May to September and in December that interrupts the activity of adult Anopheles mosquito.

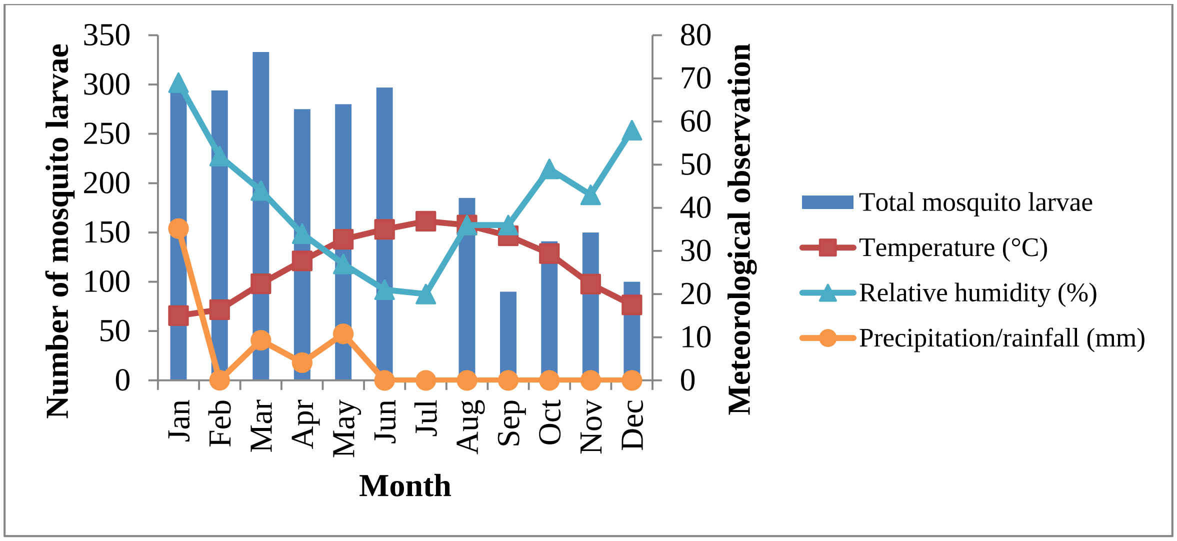

Figure 30. The relationship between climatic factors and total mosquito larvae in Al-Sarar, Eastern Province, Saudi Arabia in 2014.

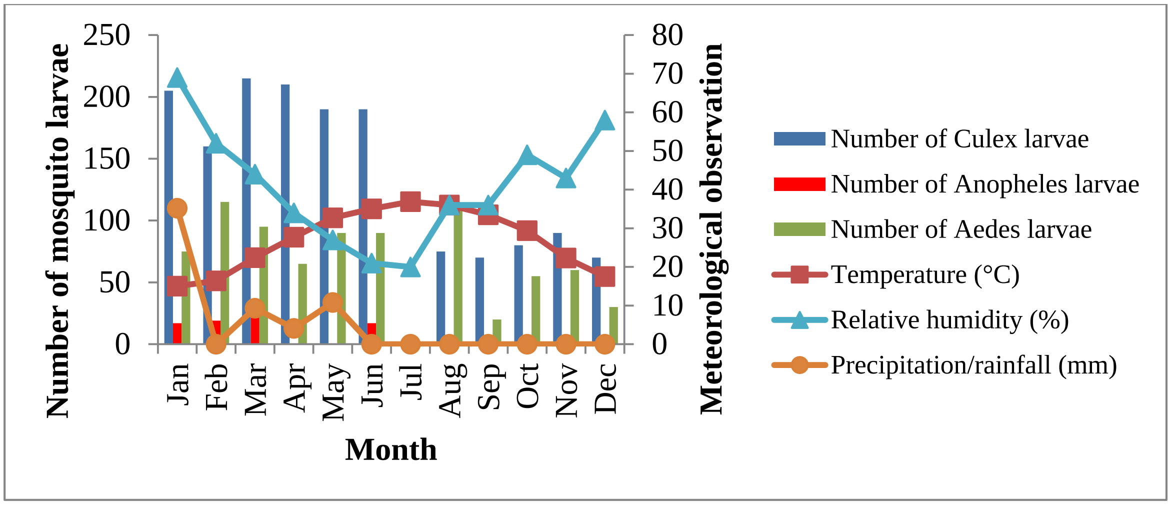

Figure 31. The relationship between climatic factors and Culex, Anopheles and Aedes larvae in Al-Sarar, Eastern Province, Saudi Arabia in 2014.

4.1.9. Eastern Province

4.1.9.1. Seasonal abundance of larval and adult mosquito

Mosquito larvae were collected throughout the year but vary in number depending on the available climatic conditions. The overall data of mosquito larvae in Eastern Province, Saudi Arabia showed that high number mosquito larvae was collected during the month of March, following the increased rainfall during the months of January and March, created more larval breeding sites together with the monthly average temperature of 22.4 ^{o}C and relative humidity of 44 % in March. However, minimum number of mosquito larvae was collected with the onset of the hottest month in July, when the monthly mean temperature was maximum (36.9 ^{o}C) and average relative humidity was minimum (20%) (Fig. 32).

Specifically, the number of mosquito larvae started to increase from January to March and reached at the peak in March, and then started to decrease until reached a minimum in July and again it started to increase with decreasing in temperature until December. In other words, high number of mosquito larvae was observed during winter season (December, January and February) characterized by cold and rainy season, followed by spring season (March, April and May) characterized with warm/cold temperatures, windy and quite rainy, and it started to decline during the onset of the hottest summer season (June, July and August) and then started to increase following the decrease in temperature during Autumn season (September, October and November) (Fig. 32).

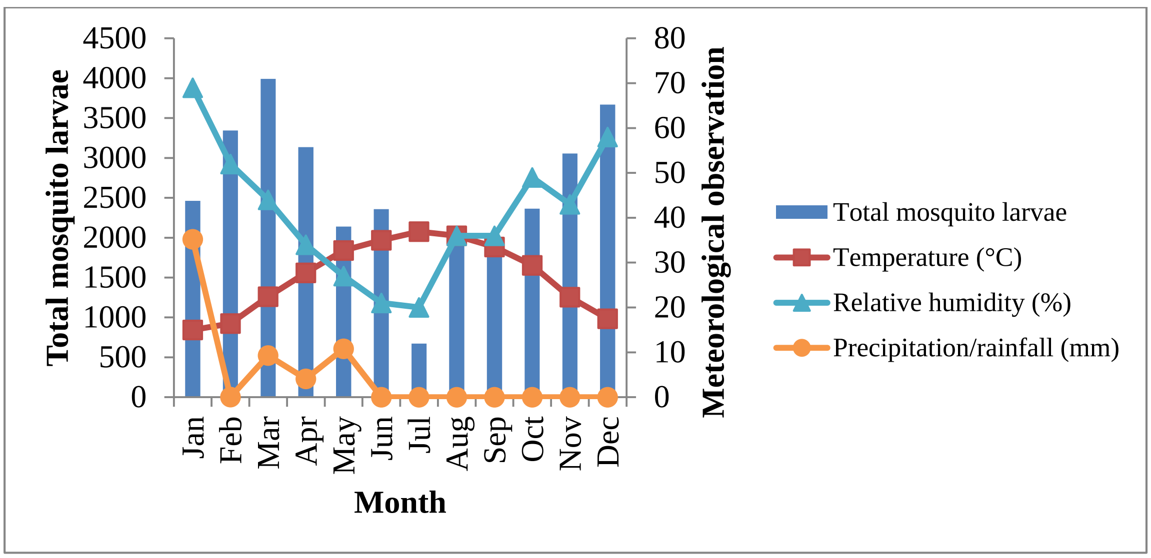

Figure 32. Relationship between climatic factors and total mosquito larvae in Eastern Province, Saudi Arabia in 2014.

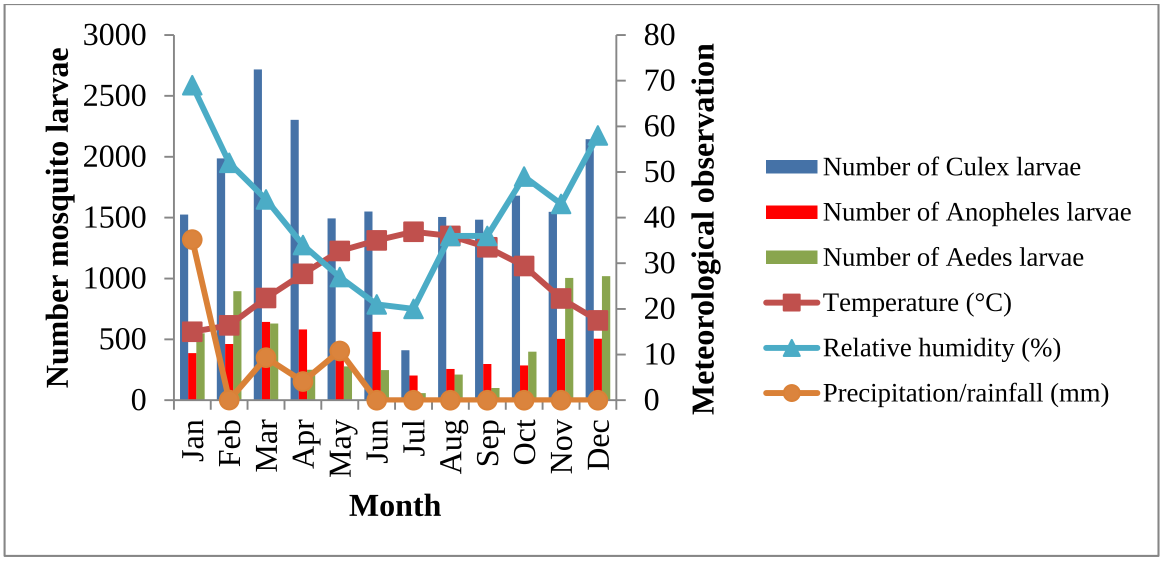

Figure 33. Relationship between climatic factors and Culex larvae, Aedes larvae and Anopheles larvae in Eastern Province, Saudi Arabia in 2014.

Strictly speaking, high number of Culex larvae and Anopheles larvae were also collected during the month of March, when the temperature was 22.4 ^{o}C and relative humidity was 44%. Increased precipitation during January and March also provided more larval breeding sites which led to attainment of high number of mosquito larvae in March. However, peak of Aedes larvae were collected in December, when the temperature was 17.5 ^{o}C and relative humidity was 58%. On the other hand, minimum number of each mosquito larvae (Culex, Aedes and Anopheles) was collected during the hottest month in July (Fig. 33).

Generally, the activity of adult mosquito was observed throughout the year but at different numbers depending on the existing climatic conditions such as temperature, relative humidity (RH) and precipitation/rainfall. A peak activity of adult mosquito was attained in December, when the temperature was 17.5 ^{o}C and the relative humidity was 58% but overall high number of adult mosquito was collected during winter season (December, January and February) when the temperature ranged between 15 °C to 17.5 °C and relative humidity ranged from 52% to 69%, and then during spring season (March, April and May), when the temperature was increasing from 22.4 °C to 32.7 °C while relative humidity was decreasing from 44% to 27%. On the other hand, the number of adult mosquito started to decrease with the onset of the dry season and reached a minimum in July, when the temperature was maximum (36.9 °C) and relative humidity was minimum (20%) (Fig. 34).

The present study showed during winter season a temperature that ranged from 15 °C to 17.5 °C and a relative humidity from 52% to 69% were conducive for the increase of adult mosquito population in Eastern Province of Saudi Arabia. The increase in rainfall from January to May, also contributed for the increase of adult mosquito activity by providing more larvae breeding sites which resulted in increasing adult mosquito during winter and spring seasons when compared to summer and autumn seasons.

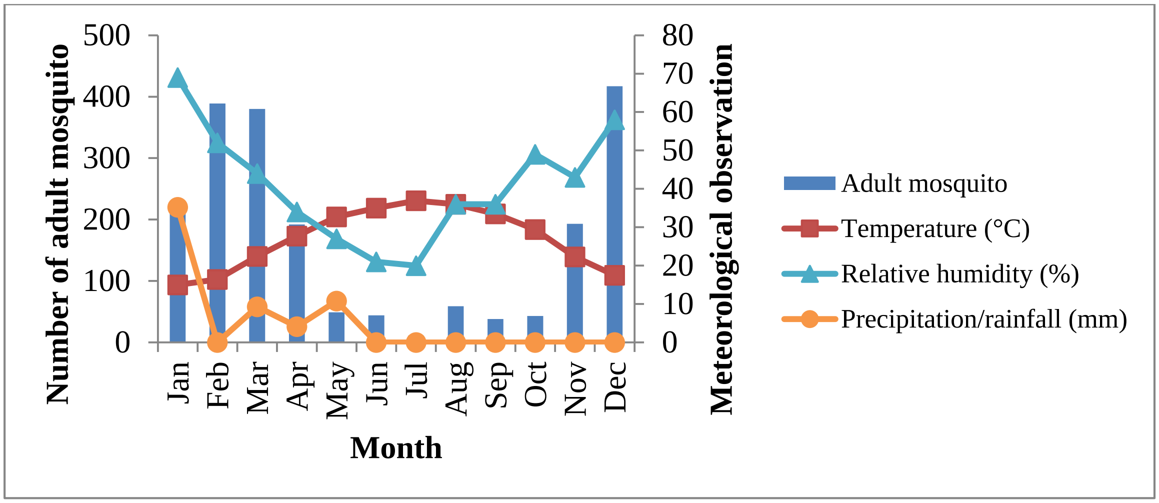

Figure 34. Relationship between climatic factors and total adult mosquito in Eastern Province, Saudi Arabia in 2014.

Though the overall data showed the presence of adult mosquito throughout the year, there were also differences in the availability by adult mosquito types. The activity of adult Culex was observed the whole year while adult anopheles mosquito was not collected during June and July in the Eastern Province of Saudi Arabia.

However, similar to the overall adult mosquito activity, peak activity of both adult Culex and adult Anopheles were observed during winter season and then during spring season. As it was noted above, the prevailing climatic factors during winter and spring seasons were the driving factors for the high activity of both adult Culex and Anopheles mosquito. The presence of rainfall from January to May also provided more larvae breeding sites which in turn increase adult mosquito activity.

Specifically speaking, high number of adult Culex were collected during February, when the temperature was 16.4 ^{o}C and relative humidity was 52% as well as during March, when the temperature was 22.4 ^{o}C and relative humidity was 44%. However, minimum number of adult Culex were collected in July, when the temperature was maximum 36.9 ^{o}C and relative humidity was minimum (20%). In case of adult Anopheles, high activity was observed during December, when the temperature was 17.5 ^{o}C and relative humidity was 58%, but no adult Anopheles was collected in June and July, when temperature was 35 ^{o}C and 36.9 ^{o}C and relative humidity was 21% and 20%, respectively (Fig. 35).

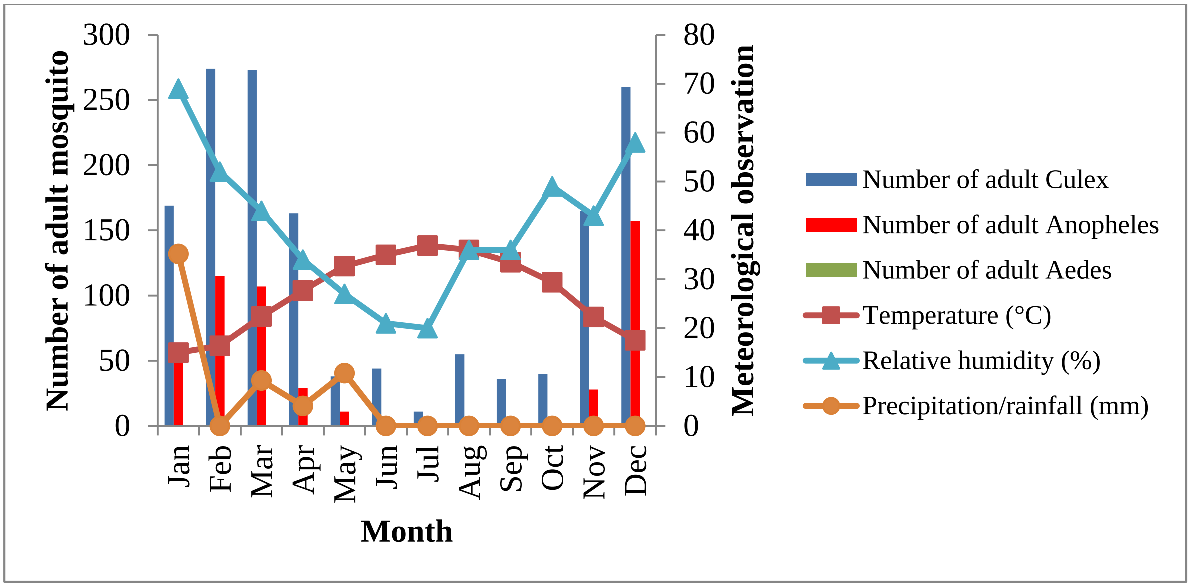

Figure 35. Relationship between climatic factors and adult Culex, Anopheles and Aedes mosquito in Eastern Province, Saudi Arabia in 2014.

4.2. Climatic Factors

The meteorological data of various parameters were obtained from the Presidency of Meteorology and Environment (PME). The climatic factors collected include temperature, relative humidity and rainfall for the year 2014. Temperature is defined as mean average of minimum and maximum temperature, measured in degree Celsius (°C). Relative humidity (RH), expressed in percentage (%), is the average monthly humidity based on the daily records. Precipitation/rainfall is the amount of rainfall in the month, measured in millimeters (Table 5).

Based on the data obtained the highest temperature (36.9 °C) was recorded during the month of July and the lowest temperature (15 °C) was recorded during the month of January. The mean annual temperature was 27.1 °C (SD ± 8.1). However, the maximum

(69%) and minimum (20%) relative humidity were observed during the month of January and July respectively. The yearly average relative humidity in the area was 40.75% (SD ± 14.79%). A total rainfall of 35.2 mm was recorded during the month of January, followed by May (10.8 mm). The average monthly rainfall was 5 mm (SD ± 10.29) in the study area (Fig. 36).

Table 5. Shows the monthly observation of meteorological data in Eastern Province, Saudi Arabia in 2014.

Climatic factors	**Month**											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (°C)	15	16.4	22.4	27.7	32.7	35	36.9	36	33.5	29.4	22.3	17.5
Relative humidity (%)	69	52	44	34	27	21	20	36	36	49	43	58
Precipitation/rainfall (mm)	35.2	0.01	9.3	4.1	10.8	0	0	0	0	0	0	0

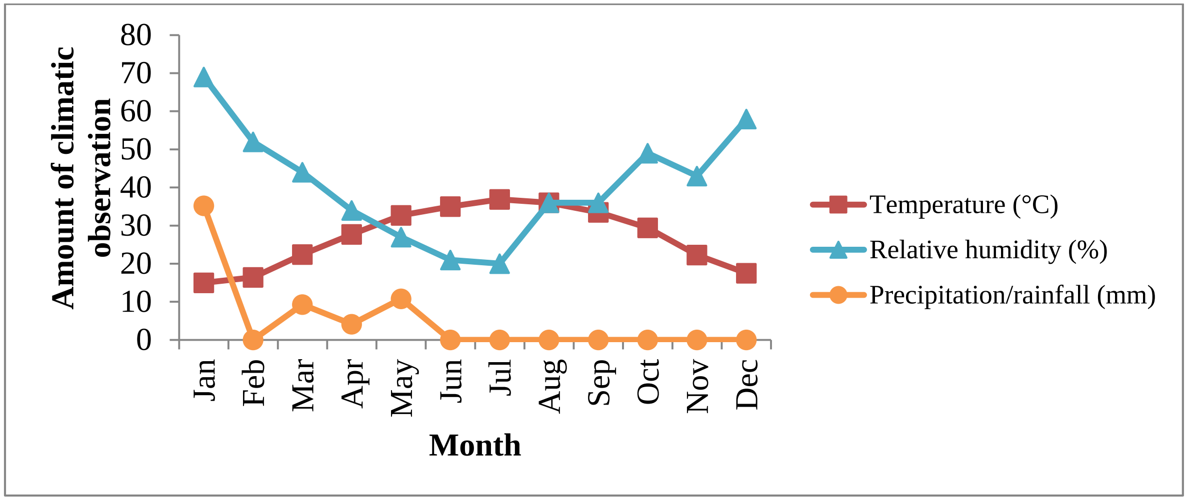

Figure 36. Monthly observation of meteorological data in Eastern Province, Saudi Arabia in 2014.

4.3. Correlation between Climatic Factors and Mosquito Larvae

The abundance of mosquito larvae is affected by the climatic factors of temperature, relative humidity and rainfall. The relationship between mosquito larvae and climatic factors are displayed for each study sites: Abu Main (Fig. 8 & 9), Umm As Sahik (Fig. 12 & 13), Safwa (Fig. 16 & 17), Al-Awjam (Fig. 18 & 19), Dammam (Fig. 22 & 23), Al-Qatif and its surrounding area (Fig. 24 & 25), Buqayq (Fig. 28 & 29), Al- Sarar (Fig. 30 & 31), and Eastern Province (Fig. 32 & 33)

As shown in Table 6, mosquito larvae abundance has strong (except little in Umm As Sahik and Al-Sarar) negative correlation with temperature but strong (except little in Umm As Sahik, Al-Awjam, Dammam and Al-Sarar) positive correlation with relative humidity. It is also evident from Table 6 that mosquito larvae abundance and precipitation has moderate positive correlation, except negative correlation in Al-Qatif and surrounding area but little positive correlation in Umm As Sahik and Dammam as well as in the overall study area of Eastern Province.

In the regression analysis, the three climatic factors (temperature, RH and rainfall) accounted 64.3% ($R^2 = 0.643$) of the variance in mosquito larvae abundance in the Eastern Province, meaning 64.3% of the variance are explained by the three parameters and the remaining 35.7% are attributed to other factors such as presence of vegetation, waste materials, water reservoirs such as ditches, and water characteristics like pH, salinity, temperature and turbidity.

Table 6. Correlation coefficient and P-Value between mosquito larvae abundance and climatic factors in study sites in Eastern Province, Saudi Arabia, 2014

Correlation and significance association	**AM**	**US**	**SA**	**AW**	**DM**	**QS**	**BU**	**AS**	**EP**
Pearson correlation									
Larvae abundance and temperature	-0.941	-0.075	-0.810	-0.441	-0.373	-0.627	-0.682	-0.350	-0.733
Larvae abundance and relative humidity	0.798	0.187	0.673	0.292	0.297	0.453	0.589	0.180	0.543
Larvae abundance and precipitation	0.534	0.202	0.537	0.356	0.199	-0.165	0.696	0.464	0.059
Significance association (P value)									
Larvae abundance and temperature	0.000**	0.816	0.001**	0.151	0.232	0.029*	0.015*	0.270	0.007**
Larvae abundance and relative humidity	0.002**	0.560	0.017*	0.357	0.349	0.139	0.044*	0.576	0.068
Larvae abundance and precipitation	0.074	0.529	0.072	0.257	0.535	0.609	0.012*	0.128	0.855

*** Correlation is significant at the 0.01 level * Correlation is significant at the 0.05 level*
Note: AM = Abu Main, US = Umm As Sahik, SA = Safwa, AW = Awjam, DM= Dammam, QS = Qatif and its surrounding area, BU = Buqayq, AS = Al-Sarar, EP = Eastern Province

4.4. Correlation between Climatic Factors and Adult Mosquito Abundance

Climatic factors (temperature, relative humidity and rainfall) have a positive or negative impact in the distribution and abundance of adult mosquito. In other words, the number of adult mosquito increases as the prevailing climatic conditions are in optimum level while it decreases when the climatic factors are above or below the optimum level.

The relationship between adult mosquito abundance and climatic factors of temperature, relative humidity and rainfall are shown in Figures 10, 11, 14, 15, 20, 21, 26, 27, 34 and 35. It is evident from Table 5 and Figure 36 that in Eastern Province the monthly average temperature was in increasing trend in the months of May, June, July, August, September and October while it was in a decreasing trend in the months of November, December, January, February, March and April for the study period.

It is also apparent from Figures 10, 14, 20, 26 and 34 that total adult mosquito abundance is highest during November, December, January, February, March and April. Similarly, in Figures 11, 15, 21, 27 and 35 the abundance of adult Culex and Anopheles was at peak during December, January, February, March and April. These results clearly indicate that average temperatures that range from 15 ^{o}C to 27.7 ^{o}C favor the increasing of mosquito abundance in study area. However, the high temperature that ranges from 29.4 ^{o}C to 36.9 ^{o}C during May, June, July, August, September and October was not suitable for fast mosquito growth.

This study also showed (Figures 10, 11, 14, 15, 20, 21, 26, 27, 34 and 35) that the average relative humidity (that ranges between 44% and 69%) was significant for the increase of mosquito abundance in the study area. In the current study, significant influence of precipitation/rainfall was also visible (Figures 10, 11, 14, 15, 20, 21, 26, 27, 34 and 35) on the abundance of adult mosquito during the rainy months though the average yearly rainfall in the study area is 4.95 mm. During the rainy month of January, February, March, April and May, more adult mosquito activity was observed but at different numbers compared to the dry seasons.

The statistical analyses performed between mosquito abundance and climatic factors are given in Table 7 for the areas of Abu Main, Umm As Sahik, Safwa, Al-Awjam, Dammam and Al-Qatif and its surrounding areas as well as for the entire Eastern Province but for Buqayq and Al Sarar, no statistical analyses were done since adult mosquitoes were not collected from these areas. It is apparent from Table 7 that the mosquito abundance has negative correlation with temperature, meaning high increase of temperature above the optimum level decrease mosquito abundance and the vice versa. However, mosquito abundance has positive correlation with relative humidity (except in Safwa), meaning as relative humidity increased, mosquito abundance also increased and the vice versa. It is also evident from Table 7 that mosquito abundance has moderate positive correlation with precipitation/rainfall (except in Abu Main and Dammam), meaning as the precipitation/rainfall increased, the number of mosquito moderately increased and the vice versa.

In the regression analysis, the three climatic factors (temperature, RH and rainfall) also explained 84.5% (R^2 = 0.845) of the variance in adult mosquito abundance in the Eastern

Province, meaning 84.5% of the variance are accounted to the three parameters and the remaining 15.5% are attributed to other factors such as presence of vegetation, waste materials, water reservoirs such as ditches, and others.

Table 7. Correlation coefficient and P-Value between adult mosquito abundance and climatic factors in study sites in Eastern Province, Saudi Arabia, 2014.

Correlation and significance association	**AM**	**US**	**SA**	**AW**	**DM**	**QS**	**EP**
Pearson Correlation							
Adult mosquito abundance and temperature	-0.597	-0.848	-0.035	-0.828	-0.186	-0.815	-0.867
Adult mosquito abundance and RH	0.467	0.757	-0.056	0.825	0.048	0.563	0.654
Adult mosquito abundance and precipitation	-0.048	0.143	0.100	0.467	-0.152	0.105	0.147
Significance (P-Value)							
Adult mosquito abundance and temperature	0.040*	0.000**	0.915	0.001**	0.562	0.001**	0.000**
Adult mosquito abundance and RH	0.126	0.004**	0.863	0.001**	0.882	0.057	0.021*
Adult mosquito abundance and precipitation	0.882	0.657	0.756	0.126	0.638	0.746	0.648

*** Correlation is significant at the 0.01 level * Correlation is significant at the 0.05 level*
Note: AM = Abu Main, US = Umm As Sahik, SA = Safwa, AW = Awjam, DM= Dammam, QS = Qatif and its surrounding area, EP = Eastern Province

4.5. Characteristics of Breeding Habitats and Associated Environmental Factors

The nature and type of the larval breeding habitats, and the presence of associated environmental factors such as floating vegetation, waste materials as well as the presence and absence of algae and biological organisms (like small fish) in the water bodies were assessed in order to characterize the mosquito larvae breeding sites in the study area.

Based on the field observation, the majority of larvae breeding habitats are ditches resulted from agricultural activities such as irrigation that create water reservoirs. It is clear that those water reservoirs such as manmade ditches resulted from irrigation activity plays substantial role in creating breeding habitats by containing stagnant waters suitable for mosquito larvae breeding and distribution in the study area. The other breeding habitats are surface waters and sewages.

Most of these breeding habitats (ditches, surface water and sewage) had floating vegetation, waste materials (plastics, papers, clothes, old tires and housing furniture), and some of them had algae and small fish. This implies that the extensive irrigation activities and poor environmental sanitation in study area contribute for the creation and availability of more breeding sites that led to the continuous presence of mosquito in the Eastern Province, Saudi Arabia.

Larval abundance varies with associated environmental factors (floating vegetation, waste materials, algae and small fish) in the breeding sites. A number of mosquito larvae were observed in breeding sites that had floating vegetation and waste materials (papers, cardboards, plastics, old tires, glass, bottles and housing furniture) or that had no small fish than those breeding sites that didn't have floating vegetation and wastes or that had small fish. This is due to the fact that the presence of vegetation and waste materials created a good access to adult mosquito to lay their eggs in the water body. In contrary, no or very limited number of mosquito larvae were seen in the breeding sites that had small fish since the small fish fed the mosquito larvae.

CHAPTER 5

DISCUSSION

The study showed that Culex larvae were the most abundant (65.54%) and were found in many habitats in the study area. The reasons for the wide distribution of Culex larvae might be due to their ability to exploit the wide range of aquatic breeding habitats for their development and survival. In addition, they can tolerate polluted and salty aquatic environments. Besides to water quality, the presence of floating vegetation and waste materials (such as plastics, papers, old tires, cloths) in the aquatic habitat also added for the wide distribution and abundance of Culex larvae since these environmental factors create appropriate access for the suitability of the aquatic environment by adult Culex mosquito to lay their eggs and for the development and survival of their larvae. Irrigation activities in the study area also contribute for the spread and abundance of the larvae since they create water reservoirs such as ditches for breeding mosquito larvae.

This finding is similar to the findings of Alahmed (2012), which reported agricultural expansion and presence of irrigation ditches/canals, pools and extensive farming contribute to the wide distribution and occurrence of mosquito in the Eastern Province of Saudi Arabia. Muturi et al. (2007) found the presence of floating vegetation in the aquatic habitat, turbid/polluted water and availability of water reservoirs such as irrigation canals/ditches in the area affect the distribution of Culex larvae and were found associated with the presence of Culex larvae. Calhoun et al. (2007) also found high Culex larvae in polluted water that is in oily/rusty water when compared to clean water.

Similarly, Ohta & Kaga (2014) reported that extensive irrigation activities encourages the growth of mosquito, lengthen the annual growing periods of mosquito and increase the maximum generation number of mosquito through the alteration of the natural water in their habitat. It also found that irrigation systems not only facilitate mosquito growth during dry seasons but also play significant role in stabilizing the growth during rainy periods.

As shown in Table 2, the total number of mosquito larvae (adult mosquito) in January, February, March, April, May, June, July, August, September, October, November and December were 2462 (221), 3345 (389), 3991 (380), 3135 (192), 2139 (49), 2358 (44), 671 (11), 1972 (59), 1881 (38), 2363 (43), 3056 (193), and 3668 (417) respectively. The data indicate that the presence of abundant mosquito larvae during November, December, February, March and April and high number of adult mosquito in the months of November, December, January, February, March and April. On the other hand, data show moderate number mosquito larvae during January, May, June, July, August, September and October and limited number of adult mosquito during May, June, July, August, September and October.

Similarly, Figures 32 and 34 show the larval and adult mosquito abundance in relation to climatic factors respectively. It is clear from these Figures that in Eastern Province the mean monthly temperature for the months of May, June, July, August, September and October is between 29.4 ^{o}C and 36.9 ^{o}C while for the months of November, December, January, February, March and April the average monthly temperature is between 15 ^{o}C and 27.7 ^{o}C. It is also clear from these Figures that high number of mosquito larvae were collected during November, December, February, March and April while high number of adult mosquito were observed during November, December, January, February, March and April. These results clearly indicates that temperatures that range from 16.4 ^{o}C to 27.7 ^{o}C are suitable for production of larvae and its survival whereas 15 ^{o}C to 27.7 ^{o}C favors for the high abundance and spread of adult mosquito.

However, during summer season the average temperature in the study area became greater than 35 ^{o}C which is not suitable for both larval and adult mosquito growth. As shown in Figures (8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34 and 35), very limited number of larval and adult mosquito were observed in July, when the temperature was 36.9 ^{o}C. Overall, high larval and adult mosquito were collected at temperature ranged from 16.4 ^{o}C to 27.7 ^{o}C and 15 ^{o}C to 27.7 ^{o}C respectively. This is consistent with the findings of Alshehri (2013), which indicated that temperatures that ranged from 20 ^{o}C to 29 ^{o}C are favorable for mosquito growth. The current study also agrees with the findings of McMichael et al. (1996), which identified that temperatures that ranged between 25 ^{o}C to 27 ^{o}C are suitable for mosquito growth.

This finding is also in agreement with Christiansen-Jucht et al. (2014), which reported that high environmental temperature decreases larval and adult survival as observed and compared at 23 ^{o}C, 27 ^{o}C 31 ^{o}C and 35 ^{o}C. Similarly, this study is comparable with the findings of Bayoh & Lindsay (2003), which found that mosquito production increases from 22 ^{o}C to 26 ^{o}C. Bayoh & Lindsay (2004) found larval survival decreased with increased temperature. The result of the study is also consistent with Westbrook et al. (2010) and

Christiansen-Jucht et al. (2014), which reported high temperatures greater than 30 ^{o}C decrease mosquito survivorship and abundance. Tian et al. (2015) found temperature range between 22 ^{o}C to 23 ^{o}C are suitable for mosquito development. Unlike to this study, Hopp & Foley (2001) and Tun-Lin et al. (2000) reported that high temperature speeds up mosquito growth and increases mosquito abundance. Alahmed (2012) also reported the effect of high temperature on mosquito abundance.

Though this study showed that temperature range between 16.4 ^{o}C to 27.7 ^{o}C and between 15 ^{o}C to 27.7 ^{o}C are favorable for larval and adult mosquito abundance respectively, the effect of temperature on mosquito growth, survival and production is difficult to predict (P. Reiter 2001).

The findings of the current study also show the effect of average relative humidity in the Eastern Province for the study year is significant for the spread and abundance of mosquito as illustrated in Figures (8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34 and 35). Different studies have indicated that relative humidity influences the survival and activities of mosquito (P. Reiter 2001; Costa et al. 2010; Alshehri 2013; Hopp & Foley 2001).

The current study indicated high relative humidity increases the larval and adult mosquito abundance and is consistent with Alshehri (2013), which found high humidity increases mosquito density. In addition, Tian et al. (2015), Bashar & Tuno (2014), Alahmed (2012) and Murty et al. (2010) reported the relationship between mosquito abundance and relative humidity. P. Reiter (2001) reported that lifespan of mosquito increases as humidity increases. Costa et al. (2010) found that both the number of female mosquito laying eggs and production of eggs (oviposition) is higher at lower temperature and higher relative humidity while Hopp & Foley (2001) found production of eggs and larvae indices increase when both temperature and humidity are high.

On the other hand, this study showed low humidity is characterized by low larval and adult mosquito abundance. During summer season minimum number of larval and adult mosquito were collected as relative humidity become low. The increased number of larval and adult mosquito were observed during October, November, December, January, February and March when relative humidity is high in study area.

Rainfall influences the number of mosquito either positively by providing more/maintaining breeding sites or negatively by flushing out mosquito larvae from small breeding sites (Byun & Webb 2012; Ceccato et al. 2005). In this study, significant influence of rainfall/precipitation was observed on larval and adult mosquito abundance though the amount of average annual rainfall in Eastern Province is 5 mm.

It is evident from Figures (8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34 and 35) that high number of larval and adult mosquito were observed during the rainy season compared to the dry season, provides more breeding sites. Overall, moderate positive correlation between mosquito abundance and rainfall was noticed in the study area, which is consistent with (Koenraadt et al. 2004; Hu et al. 2006) Several studies have also demonstrated the relationship between mosquito abundance and rainfall (Tian et al. 2015; Alahmed 2012; Alshehri 2013; Bashar & Tuno 2014; Murty et al. 2010).

Overall, mosquito larvae abundance has negative correlation with temperature in general, but strong negative correlation in Abu Main, Safwa, Al-Qatif and Buqayq. Larva abundance has positive correlation with relative humidity, with highest correlation values (0.798, 0.673, and 0.589) in Abu Main, Safwa and Buqayq respectively. Mosquito larvae abundance and precipitation has moderate to low positive correlation, with the exception of negative correlation in Al-Qatif. The regression model of the three climatic factors (temperature, RH and rainfall) accounted is 64.3% ($R^2 = 0.643$) of the variance in mosquito larvae abundance in the Eastern Province. 64.3% of the variance explained by the 3 parameters and the remaining 35.7% attributed to other factors such as presence of vegetation, waste materials and water reservoirs such as ditches. The regression model for three climatic factors (temperature, RH and rainfall) explained 84.5% ($R^2 = 0.845$) of the variance in adult mosquito abundance in the Eastern Province. This mean that 84.5% of the variance are accounted to the three parameters and the remaining 15.5% attributed to other factors such as presence of vegetation, waste materials, water reservoirs, ditches, and others.

In comparisons of the two regression models (larvae and adults) and climatic factors, it seems that larvae is more influenced by presence of vegetation, waste material, water reservoirs and diches. The presence of floating and terrestrial vegetation, poor environmental sanitation and extensive irrigation activities that creates water reservoirs such as ditches are among the major environmental factors for mosquito larvae abundance and their wide distribution in many habitats (Chaikoolvatana et al. 2007; Alahmed 2012; Ohta & Kaga 2014; Calhoun et al. 2007).

In the current study, some mosquito types were collected as larvae but not as adult. Specifically, Aedes mosquito was collected as larvae but not as adult throughout the year in the study area. Similarly, adult Culex and Anopheles were not collected from Buqayq and Al-Sarar throughout the year. Unlike to this, both larval and adult Anopheles were not collected from Dammam area during the study period. The reason might be due to the differences in adult behavior such as feeding and resting behavior as some mosquito species are indoor feeders and indoor resting and they do not come close to the trapping or sampling location placed outside houses during the data collection period while other mosquito types may be outdoor feeders and indoor resting. This agrees with the findings of Alahmed (2012), which explained unavailability of larvae or adult of some mosquito species in certain sites is attributed to the adult behavior as some of the mosquitoes are indoor feeder and they don't come near light traps which were placed outside houses.

High number of larval and adult mosquito continues to occur due to lack of standard mosquito control policies and poor sanitation (Chaikoolvatana et al. 2007). In Eastern Province, extensive agricultural (irrigation) activities and poor environmental sanitation together with lack of standard mosquito control policies attributes for the continuous presence of mosquito though there is a continuous mosquito control activities in the area. This is consistent with findings of (Ohta & Kaga 2014; Alahmed 2012; Calhoun et al. 2007).

In the present study, Global Positioning System (GPS) under Geographic Information System (GIS) was used to map the mosquito larvae breeding sites in Eastern Province of Saudi Arabia. Similarly, GPS with GIS was used to mapping and modelling mosquito vector habitat, their distribution and mosquito-borne diseases distribution in several studies

(Rydzanicz et al. 2011; Palaniyandi et al. 2014; M Palaniyandi 2014b; S. A. Agarwal et al. 2012; Zou et al. 2006). GIS application is not only enables updating, mapping and modelling mosquito vector distribution but also crucial in developing forecasting maps for planning, mosquito surveillance, mosquito control, decision making and data management. This implies that the maps and models developed using GIS can be used by every individuals and organizations looking for information so as to use for mosquito control activities and health information management (Palaniyandi et al. 2014; M Palaniyandi 2014b; Rydzanicz et al. 2011).

Several studies outlined that understanding climatic factors (temperature, relative humidity and rainfall) that control over mosquito vector distribution and abundance is fundamental in mosquito control activity since it helps to predict, plan and implement preventive and control measures. However, studying the relationship between mosquito and climatic factors is not sufficient for effective mosquito control. For this reason, strengthening this information using GIS technology is a key for improved and advanced mosquito control activities and control of MBDs as the application address some limitations regarding larval and adult mosquito location and assist for updating, editing, collecting and analyzing mosquito data and land use (Rydzanicz et al. 2011; S. A. Agarwal et al. 2012; Chaikoolvatana et al. 2007). Thus, the GIS technology makes the mosquito control activities easier, more effective and efficient than the traditional methods of mosquito control (Palaniyandi et al. 2014; M Palaniyandi 2014a, 2014b; Zou et al. 2006).

On the other hand, there are other environmental factors such as vegetation cover, irrigation activities, ecological characteristics of the breeding sites (pH, salinity, water temperature, turbidity and algae/fish) and poor environmental sanitation that have significant impact on mosquito distribution and abundance. Hence, continuous public awareness about mosquito control, drainage of stagnant waters, and proper disposal of wastes is needed for comprehensive mosquito control program.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The findings of the study demonstrated the relationship between mosquito abundance and environmental/climatic factors (temperature, relative humidity and rainfall) and found strong negative correlation between mosquito abundance and temperature, while strong and moderate positive correlation between relative humidity and rainfall, respectively. High environmental temperatures were found associated with the low mosquito abundance. On the other hand, high and moderate mosquito vector abundance were observed at high relative humidity and during rainy months, respectively, in the study area. In addition, the study identified the potential hotspots of larvae breeding sites with detailed map delineating the characteristics of the habitats.

Environmental/climatic factors (temperature, relative humidity and rainfall) govern the increase and decrease of the mosquito abundance by affecting the production, development and survival stages of larval and adult mosquito. Understanding the effects of these factors on mosquito vectors has a significant role in mosquito control. It is possible to predict the mosquito abundance by forecasting the temperature, relative humidity and rainfall and then to plan and implement the current and future mosquito control activities. Similarly, GIS application in mosquito control activities address some limitations regarding larval and adult mosquito location and assist for updating, editing, collecting and analyzing on mosquito data and land use.

Therefore, understanding the relationship between the mosquito vectors and environmental/climatic factors (temperature, relative humidity and rainfall), and supplementing this information using GIS application to identify and mapping the potential larval breeding sites, is a key for effective mosquito control in order to reduce, prevent and avoid morbidity and mortality caused by mosquito-borne diseases transmitted by mosquito vectors.

6.2. Recommendations

Based on the findings, the following recommendations are given:

1. Mosquito control programs should be supported by GIS application in order to improve the routine mosquito control activities
2. Proper drainage of water from the diches as well as filling and avoiding of stagnant waters that serve for mosquito larvae breeding sites
3. Proper disposal of solid wastes and improving environmental sanitation (such as proper disposal of solid wastes), and construction and regular maintenance of sewer lines.
4. There should be inter-sectroral collaboration between ministry of agriculture and ministry of health to consider irrigation activities not to serve as larvae breeding sites and to apply environmental friendly mosquito control measures.

5. Public awareness and public education should be given about mosquitoes, the diseases they transmitted (MBDs) and the preventive and control methods against mosquito vectors.
6. Further study should be carried out to assess the effect of irrigation systems on the spatial and temporal distribution of mosquito vectors, and ecological characteristics of larvae breeding habitat.
7. Further study on spatial-temporal models using environmental factors (such as soil types and vegetation) as well as study on the productive models of mosquito using GIS and remote sensing or GPS.

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APPENDIX

Appendix A. Characteristics of mosquito breeding sites in Eastern Province, Saudi Arabia, 2014

ID	X	Y	Area	Mosquito	Type	L (m)	W (m)	Nearest house	Other observation
1	26.66530000	49.82961667	Abu Main	Not found	Ditch	316	3	101-200 m	Vegetation, wastes [a, b]
2	26.66725000	49.83025000	Abu Main	Cx, Ae	Ditch	270	3	101-200 m	Vegetation, wastes [a, b]
3	26.66830000	49.83043333	Abu Main	Cx, Ae, An	Ditch	2000	3	101-200 m	Vegetation, wastes [a, b], fish
4	26.67161667	49.82973333	Abu Main	Not found	Farm	200	3	101-200 m	Vegetation, wastes [a, b], fish
5	26.67395000	49.82686667	Abu Main	Cx, Ae, An	Ditch	200	2.5	1-100 m	Vegetation, wastes [a, b]
6	26.66685000	49.80681667	Abu Main	Cx	Sewage	30	0.5	1-100 m	Vegetation
7	26.66858333	49.80713333	Abu Main	Cx, An	Farm	50	1	1-100 m	Vegetation
8	26.65550000	49.79743333	Abu Main	Not found	Ground water	12	5	101-200 m	Vegetation, wastes [a, b]
9	26.65561667	49.79143333	Abu Main	Not found	Farm	400	3	1-100 m	Vegetation
10	26.65421667	49.79016667	Abu Main	Not found	Farm	400	3	1-100 m	Vegetation, wastes [a, b]
11	26.55483333	49.94338333	Al-Awjam	Cx	Surface water	200	15	1-100 m	Vegetation, wastes [a, b]
12	26.55166667	49.94565000	Al-Awjam	Cx, Ae	Surface water	130	30	1-100 m	Vegetation, waste [a]
13	26.55196667	49.94595000	Al-Awjam	Not found	Surface water	40	15	1-100 m	Vegetation, wastes [a, b]
14	26.54901667	49.94531667	Al-Awjam	Cx, Ae	Ditch	300	3	1-100 m	Vegetation, waste [a]
15	26.54785000	49.94040000	Al-Awjam	Cx, An	Ditch	300	3	101-200 m	Vegetation, waste [a]
16	26.54730000	49.94281667	Al-Awjam	Cx, Ae	Ditch	70	15	101-200 m	Vegetation, waste [a]
17	26.54588333	49.94285000	Al-Awjam	Cx, Ae, An	Ditch	40	1.5	1-100 m	Vegetation, waste [a]
18	26.54485000	49.94303333	Al-Awjam	Cx, An	Ditch	40	1.5	1-100 m	Vegetation, waste [a]
19	26.54268333	49.94423333	Al-Awjam	Not found	Ditch	250	2	1-100 m	Vegetation, waste [a]
20	26.56508333	49.94716667	Al-Awjam	Not found	Ditch	10	8	1-100 m	Vegetation, waste [a]
21	26.56341667	49.94690000	Al-Awjam	Cx, Ae	Ditch	5	2.5	1-100 m	Vegetation, waste [a]
22	26.55758333	49.93471667	Al-Awjam	Cx, Ae	Ditch	30	1.5	1-100 m	Vegetation, waste [a]

23	26.55780000	49.93475000	Al-Awjam	Cx, Ae, An	Ditch	30	1.5	1-100 m	Vegetation, waste [a]
24	26.55838333	49.93460000	Al-Awjam	Cx, An	Ditch	50	2.5	1-100 m	Vegetation, waste [a]
25	26.56123333	49.93706667	Al-Awjam	Cx, An	Ditch	15	3	1-100 m	Vegetation, waste [a]
26	26.56125000	49.93776667	Al-Awjam	Not found	Ditch	15	1	1-100 m	Vegetation
27	26.56280000	49.93863333	Al-Awjam	Cx, An	Well	1.5	1	1-100 m	Vegetation
28	26.56283333	49.93893333	Al-Awjam	Cx, An	Well	1.5	1	1-100 m	Vegetation
29	26.56276667	49.93886667	Al-Awjam	Cx, An	Well	1.5	1	1-100 m	Vegetation
30	26.56293333	49.93910000	Al-Awjam	Cx, An	Well	1.5	1	1-100 m	Vegetation
31	26.56683333	49.94455000	Al-Awjam	Cx, An	Sewage	20	2	1-100 m	Vegetation, waste [a]
32	26.56941667	49.93810000	Al-Awjam	Not found	Sewage	25	2	1-100 m	Vegetation, waste [a]
33	26.56988333	49.93863333	Al-Awjam	Cx	Ditch	20	2	1-100 m	Vegetation
34	26.57020000	49.93798333	Al-Awjam	Cx	Ditch	15	4	1-100 m	Vegetation, waste [a]
35	26.57005000	49.93655000	Al-Awjam	Not found	Surface water	700	400	101-200 m	Vegetation, waste [a]
36	26.56916667	49.93688333	Al-Awjam	Not found	Ditch	45	1	1-100 m	Vegetation, waste [a]
37	26.57001667	49.94000000	Al-Awjam	Not found	Ditch	3	1	1-100 m	Vegetation, fish
38	26.57165000	49.93901667	Al-Awjam	Cx, An	Ditch	35	2	1-100 m	Vegetation
39	26.57083333	49.94021667	Al-Awjam	Cx	Stagnant water	3	1	1-100 m	Vegetation, waste [a]
40	26.57090000	49.94036667	Al-Awjam	Cx, An	Ditch	50	2	1-100 m	Vegetation, waste [a]
41	26.60363333	49.98561667	Al Awamiyah	Not found	Stagnant water	100	0.5	1-100 m	Vegetation, waste [a]
42	26.60193333	49.98715000	Al Awamiyah	Not found	Ditch	15	0.5	101-200 m	Vegetation, small fish
43	26.60190000	49.99081667	Al Awamiyah	Cx, Ae, An	Stagnant water	70	1	1-100 m	Vegetation, waste [a]
44	26.60071667	49.99085000	Al Awamiyah	Cx, An	Ditch	20	0.5	1-100 m	Vegetation, waste [a]
45	26.59996667	49.99803333	Al Awamiyah	Not found	Ditch	100	0.5	1-100 m	Vegetation, small fish
46	26.59646667	49.99588333	Al Awamiyah	Cx	Ditch	150	1	1-100 m	Vegetation, waste [a]
47	26.59221667	49.99620000	Al Awamiyah	Cx, Ae, An	Ditch	80	0.5	101-200 m	Vegetation, waste [a]
48	26.59223333	49.99638333	Al Awamiyah	Cx, Ae	Ditch	50	1	101-200 m	Vegetation, waste [a]
49	26.59161667	49.99161667	Al Awamiyah	Not found	Ditch	70	0.5	1-100 m	Vegetation, waste [a]
50	26.59676667	49.98501667	Al Awamiyah	Not found	Surface water	35	8	1-100 m	Vegetation, small fish

51	26.59231667	49.99275000	Al Awamiyah	Cx, Ae	Ditch	300	0.5	1-100 m	Vegetation, waste [a]
52	26.59055000	49.99043333	Al Awamiyah	Cx, An	Ditch	150	1	1-100 m	Vegetation, waste [a]
53	26.59090000	49.98993333	Al Awamiyah	Not found	Ditch	50	0.5	1-100 m	Vegetation, small fish
54	26.59093333	49.98888333	Al Awamiyah	Not found	Ditch	50	0.5	101-200 m	Vegetation, waste [a]
55	26.58985000	49.99625000	Al Awamiyah	Cx, Ae	Ditch	70	0.5	1-100 m	Vegetation, waste [a]
56	26.58473333	49.99670000	Al Awamiyah	Not found	Ditch	100	10	1-100 m	Construction wastes
57	26.58700000	49.99013333	Al Awamiyah	Not found	Ditch	70	1	1-100 m	Vegetation, wastes [a, b]
58	26.58790000	49.98941667	Al Awamiyah	Cx, Ae	Ditch	70	1	1-100 m	Vegetation
59	26.58511667	49.98671667	Al Awamiyah	Not found	Ditch	150	1	1-100 m	Vegetation
60	26.58151667	49.98521667	Al Awamiyah	Cx, Ae, An	Ditch	80	1	101-200 m	Vegetation, wastes [a, b]
61	26.58221667	49.98575000	Al Awamiyah	Not found	Ditch	200	2	1-100 m	Vegetation
62	26.57766667	49.99540000	Al Bahari	Cx, Ae, An	Farm	40	3	1-100 m	Vegetation
63	26.57765000	49.99738333	Al Bahari	Cx, Ae, An	Ditch	150	1.5	1-100 m	Vegetation
64	26.57353333	50.00076667	Al Bahari	Not found	Stagnant water	15	3	1-100 m	Vegetation, waste [a]
65	26.57393333	50.00005000	Al Bahari	Cx, Ae	Ditch	85	2.5	1-100 m	Vegetation, wastes [a, b]
66	26.57383333	49.99873333	Al Bahari	Not found	Ditch	35	2.5	1-100 m	Vegetation, waste [a]
67	26.57523333	49.99840000	Al Bahari	Cx, Ae, An	Ditch	40	2.5	1-100 m	Vegetation, waste [a]
68	26.57586667	49.99808333	Al Bahari	Not found	Ditch	65	2	101-200 m	Vegetation, waste [a]
69	26.57401667	49.99653333	Al Bahari	Not found	Farm	25	2.5	1-100 m	Vegetation, waste [a]
70	26.53390000	49.99828333	Al Hilah	Not found	Ditch	231	1.5	1-100 m	Vegetation, waste [a]
71	26.54196667	50.00006667	Al Hilah	Cx, An	Ditch	123	1.5	1-100 m	Vegetation, waste [a]
72	26.54180000	50.00081667	Al Hilah	Cx, An	Ditch	110	1.5	1-100 m	Vegetation, waste [a]
73	26.53533333	50.00203333	Al Hilah	Not found	Ditch	65	2	1-100 m	Vegetation, waste [a]
74	26.53405000	50.00253333	Al Hilah	Not found	Ditch	233	1.5	1-100 m	Vegetation, small fish
75	26.53488333	49.99950000	Al Hilah	Cx, Ae, An	Ditch	70	1.5	1-100 m	Vegetation, waste [a]
76	26.53666667	49.99725000	Al Hilah	Not found	Ditch	115	1.5	1-100 m	Vegetation, waste [a]
77	26.53415000	49.99391667	Al Hilah	Cx, Ae, An	Ditch	150	1.5	1-100 m	Vegetation, waste [a]
78	26.53433333	49.99590000	Al Hilah	Not found	Ditch	76	1.5	1-100 m	Vegetation, waste [a]

79	26.53293333	49.99721667	Al Hilah	Not found	Ditch/farm	45	2	101-200 m	Vegetation, small fish
80	26.53183333	49.99716667	Al Hilah	Not found	Ditch	50	2	1-100 m	Vegetation, waste [a]
81	26.52938333	49.99035000	Al- Jarudiyah	Not found	Ditch	170	2	1-100 m	Vegetation, waste [a]
82	26.53125000	49.99130000	Al- Jarudiyah	Cx, Ae, An	Ditch	150	1.5	1-100 m	Vegetation, small fish
83	26.53285000	49.99125000	Al- Jarudiyah	Not found	Ditch	105	1.5	1-100 m	Vegetation, wastes [a, b]
84	26.53563333	49.99070000	Al- Jarudiyah	Cx, Ae, An	Ditch	70	1.5	1-100 m	Vegetation, wastes [a, b]
85	26.53918333	49.98953333	Al- Jarudiyah	Not found	Ditch	70	2	1-100 m	Vegetation, waste [a]
86	26.53510000	49.98243333	Al- Jarudiyah	Not found	Ditch	35	2	1-100 m	Vegetation, waste [a]
87	26.53333333	49.98648333	Al- Jarudiyah	Cx	Ditch	15	8	1-100 m	Vegetation, waste [a]
88	26.50728333	49.99456667	Al-Jesh	Cx, Ae, An	Ditch/farm	165	1.5	1-100 m	Wastes [a, b, c]
89	26.50071667	50.00161667	Al-Jesh	Cx	Ditch/farm	300	2	1-100 m	Vegetation, wastes [a, b]
90	26.50725000	49.98968333	Al-Jesh	Cx, Ae, An	Ditch	135	2.5	1-100 m	Vegetation, wastes [a, b]
91	26.50490000	49.99110000	Al-Jesh	Not found	Ditch/farm	95	1.5	1-100 m	Vegetation, wastes [a, b]
92	26.50143333	49.99136667	Al-Jesh	Cx, Ae	Ditch	110	2	1-100 m	Vegetation, waste [a]
93	26.50023333	49.99221667	Al-Jesh	Not found	Ditch	110	2	101-200 m	Vegetation, waste [a]
94	26.49923333	49.99368333	Al-Jesh	Cx, Ae, An	Ditch/farm	115	1.5	1-100 m	Vegetation, waste [a]
95	26.49945000	49.99528333	Al-Jesh	Cx	Ditch	65	2.5	1-100 m	Vegetation, waste [a]
96	26.49985000	49.99826667	Al-Jesh	Not found	Ditch	256	3	1-100 m	Vegetation, small fish
97	26.50170000	50.00055000	Al-Jesh	Cx, Ae, An	Ditch	14	2.5	1-100 m	Vegetation, waste [a]
98	26.50146667	50.00041667	Al-Jesh	Not found	Ditch	45	2	1-100 m	Vegetation, small fish
99	26.57778333	49.99171667	Al Qudaih	Cx	Ditch	70	3	1-100 m	Vegetation, waste [a]
100	26.57745000	49.99138333	Al Qudaih	Not found	Ditch	180	2	1-100 m	Vegetation, small fish
101	26.57680000	49.99150000	Al Qudaih	Cx, Ae, An	Ditch	80	2	1-100 m	Vegetation, waste [a]
102	26.57741667	49.98925000	Al Qudaih	Not found	Ditch	250	2	1-100 m	Vegetation, small fish
103	26.57663333	49.98935000	Al Qudaih	Not found	Ditch	170	2	1-100 m	Vegetation, wastes [a, b]
104	26.57520000	49.98873333	Al Qudaih	Cx	Ditch	245	2	1-100 m	Vegetation, wastes [a, b]
105	26.57453333	49.98790000	Al Qudaih	Cx, Ae, An	Ditch	350	2	1-100 m	Vegetation, waste [a]

106	26.57371667	49.98795000	Al Qudaih	Cx, Ae, An	Ditch	50	2	101-200 m	Vegetation, waste [a]
107	26.57481667	49.98523333	Al Qudaih	Cx, Ae, An	Ditch	270	2	101-200 m	Vegetation, small fish
108	26.57406667	49.98518333	Al Qudaih	Not found	Ditch	85	2	1-100 m	Vegetation, wastes [a, b]
109	26.56890000	49.98358333	Al Qudaih	Cx, Ae, An	Ditch	150	2	1-100 m	Vegetation, wastes [a, b]
110	26.56916667	49.99015000	Al Qudaih	Not found	Ditch	75	6	1-100 m	Vegetation, wastes [a, b]
111	26.50880000	50.00796667	Al-Mallahah	Cx, Ae	Ditch	550	5	1-100 m	Vegetation, waste [a]
112	26.51621667	50.00426667	Al-Mallahah	Cx, Ae, An	Ditch	185	2	1-100 m	Vegetation, waste [a]
113	26.50888333	50.00805000	Al-Mallahah	Not found	Ditch	450	2	1-100 m	Wastes [a, b, c]
114	26.51296667	50.00181667	Al-Mallahah	Cx, Ae, An	Ditch	65	2	1-100 m	Vegetation, wastes [a, b]
115	26.51266667	50.00393333	Al-Mallahah	Not found	Ditch/farm	40	2	1-100 m	Vegetation, wastes [a, b]
116	26.51271667	50.00373333	Al-Mallahah	Not found	Ditch/farm	15	2	1-100 m	Vegetation, wastes [a, b]
117	26.51178333	50.00513333	Al-Mallahah	Not found	Stagnant water	15	7	101-200 m	Vegetation, wastes [a, b]
118	26.51480000	50.00731667	Al-Mallahah	Cx, Ae, An	Ditch/farm	70	2	1-100 m	Vegetation, waste [a]
119	26.50881667	50.00563333	Al-Mallahah	Cx, Ae, An	Ditch	175	1.5	1-100 m	Vegetation, waste [a]
120	26.50870000	50.00206667	Al-Mallahah	Cx	Ditch/farm	380	2	1-100 m	Vegetation, waste [a]
121	26.51221667	50.00006667	Al-Mallahah	Cx, Ae	Ditch	85	2	1-100 m	Vegetation, waste [a]
122	26.96603333	48.39695000	Al-Sarar	Cx, Ae, An	Surface water	11	7	201-400 m	Vegetation, waste [a]
123	26.97365000	48.39726667	Al-Sarar	Cx, Ae, An	Surface water	65	12	401-800 m	Vegetation, waste [a]
124	26.97680000	48.39631667	Al-Sarar	Cx, Ae, An	Surface water	15	3	201-400 m	Vegetation, waste [a]
125	26.98785000	48.38808333	Al-Sarar	Cx, Ae, An	Surface water	75	35	1-100 m	Waste [a]
126	26.98916667	48.38423333	Al-Sarar	Cx, Ae, An	Surface water	300	102	1-100 m	Wastes [a, b]
127	26.98846667	48.38265000	Al-Sarar	Cx, Ae, An	Surface water	45	43	201-400 m	Wastes [a, b]
128	26.87710000	48.71730000	Al-Sarar	Cx, Ae	Surface water	32	11	1-100 m	Wastes [a, b]
129	26.87628333	48.70685000	Al-Sarar	Cx, Ae	Surface water	51	19	> 800 m	Vegetation
130	26.87588333	48.71570000	Al-Sarar	Cx, Ae	Surface water	110	75	1-100 m	Waste a
131	26.87995000	48.72023333	Al-Sarar	Cx, Ae	Surface water	23	21	201-400 m	Wastes [a, b]
132	26.87753333	48.71838333	Al-Sarar	Cx, Ae	Surface water	23	13	1-100 m	Wastes [a, b]

133	26.93416667	48.57955000	Al-Sarar	Cx, Ae	Surface water	15	3	1-100 m	Nothing
134	26.93456667	48.57676667	Al-Sarar	Cx, Ae	Surface water	17	2	1-100 m	Nothing
135	26.81211667	48.33766667	Al-Sarar	Cx	Surface water	25	13	201-400 m	Nothing
136	26.80211667	48.33768333	Al-Sarar	Not found	Surface water	85	35	> 800 m	Vegetation, waste [a]
137	26.97806667	48.51835000	Al-Sarar	Cx, Ae, An	Surface water	4	3	> 800 m	Vegetation, wastes [a, b]
138	26.96923333	48.46220000	Al-Sarar	Not found	Surface water	45	28	> 800 m	Vegetation
139	27.01718333	48.45540000	Al-Sarar	Not found	Ditch	39	2	> 800 m	Vegetation, waste [a]
140	27.02261667	48.46871667	Al-Sarar	Cx	Ditch	156	2	> 800 m	Vegetation, waste [a]
141	27.02518333	48.45973333	Al-Sarar	Not found	Surface water	11	2	> 800 m	Vegetation, waste [a]
142	26.98313333	48.85043333	Al-Sarar	Cx, An	Surface water	265	136	> 800 m	Vegetation, waste [a]
143	26.97290000	48.85181667	Al-Sarar	Cx, An	Surface water	68	24	1-100 m	Vegetation, waste [a]
144	26.90976667	48.41886667	Al-Sarar	Not found	Surface water	25	5	1-100 m	Vegetation, waste [a]
145	26.91171667	48.41540000	Al-Sarar	Cx, Ae	Ditch	32	2	1-100 m	Vegetation, waste [a]
146	27.15605000	48.61596667	Al-Sarar	Cx, An	Surface water	23	16	> 800 m	Nothing
147	27.16160000	48.60196667	Al-Sarar	Cx, An	Surface water	2	1.5	1-100 m	Vegetation, waste [a]
148	27.27553333	48.43113333	Al-Sarar	Cx	Surface water	111	36	> 800 m	Nothing
149	27.27455000	48.43331667	Al-Sarar	Cx	Surface water	123	19	> 800 m	Nothing
150	27.37691667	48.33810000	Al-Sarar	Cx	Surface water	15	5	1-100 m	Vegetation
151	27.37828333	48.34058333	Al-Sarar	Cx	Surface water	4	3	201-400 m	Vegetation
152	25.92380000	49.63176667	Buqayq	Cx, Ae, An	Surface water	155	113	> 800 m	Vegetation, waste [a]
153	25.92715000	49.63511667	Buqayq	Cx, Ae, An	Ditch	38	2	> 800 m	Vegetation, waste [a]
154	25.92845000	49.63561667	Buqayq	Cx,Ae, An	Surface water	13	5	> 800 m	Vegetation, waste [a]
155	25.92410000	49.63600000	Buqayq	Cx, Ae, An	Ditch	97	3	> 800 m	Vegetation, wastes [a, b]
156	25.92048333	49.64248333	Buqayq	Cx, Ae, An	Stagnant water	0.5	0.5	> 800 m	Vegetation, wastes [a, b]
157	25.96635000	49.56410000	Buqayq	Cx, Ae, An	Ditch	179	3	101-200 m	Vegetation, wastes [a, b]
158	25.96746667	49.56323333	Buqayq	Cx, Ae, An	Surface water	105	4	101-200 m	Vegetation, wastes [a, b]
159	25.96895000	49.56461667	Buqayq	Not found	Ditch	152	1.5	101-200 m	Vegetation, waste [a]
160	25.97735000	49.48523333	Buqayq	Cx	Surface water	81	48	101-200 m	Vegetation, waste [a]

161	25.94318333	49.49971667	Buqayq	Cx, Ae, An	Surface water	7	5	101-200 m	Vegetation, waste [a]
162	25.93916667	49.49966667	Buqayq	Cx, Ae, An	Surface water	157	115	401-800 m	Vegetation, waste [a]
163	25.94218333	49.49490000	Buqayq	Cx	Surface water	25	4	401-800 m	Vegetation, waste [a]
164	25.94176667	49.50023333	Buqayq	Cx	Surface water	270	115	401-800 m	Vegetation, waste [a]
165	25.86635000	49.59215000	Buqayq	Cx, Ae, An	Stagnant water	15	9	1-100 m	Vegetation, waste [a]
166	25.86666667	49.59453333	Buqayq	Cx, Ae, An	Stagnant water	65	18	201-400 m	Vegetation, waste [a]
167	25.94626667	49.42005000	Buqayq	Cx, Ae	Surface water	35	19	1-100 m	Vegetation, wastes [a, b]
168	25.94461667	49.41940000	Buqayq	Cx, Ae	Sewage	13	2	1-100 m	Vegetation, wastes [a, b]
169	25.98816667	49.39260000	Buqayq	Cx, Ae	Stagnant water	7	5	1-100 m	Vegetation, wastes [a, b]
170	25.98821667	49.39158333	Buqayq	Cx, Ae	Stagnant water	6	4	1-100 m	Vegetation, wastes [a, b]
171	26.02795000	49.45710000	Buqayq	Cx, Ae, An	Surface water	26	23	1-100 m	Vegetation, waste [a]
172	26.02716667	49.45813333	Buqayq	Cx, Ae, An	Surface water	127	7	1-100 m	Vegetation, waste [a]
173	26.06278333	49.45066667	Buqayq	Cx, Ae, An	Surface water	11	6	> 800 m	Vegetation, waste [a]
174	26.07230000	49.44625000	Buqayq	Cx, Ae, An	Surface water	7	6	1-100 m	Vegetation, waste [a]
175	26.07223333	49.44955000	Buqayq	Cx, Ae, An	Surface water	29	1	1-100 m	Vegetation, waste [a]
176	26.06721667	49.44810000	Buqayq	Cx, Ae, An	Surface water	21	10	401-800 m	Vegetation, waste [a]
177	26.09366667	49.43866667	Buqayq	Cx, Ae, An	Surface water	19	13	> 800 m	Vegetation, waste [a]
178	25.94981667	49.57810000	Buqayq	Cx, Ae	Surface water	25	6	1-100 m	Vegetation, waste [a]
179	25.94401667	49.57315000	Buqayq	Cx, Ae, An	Surface water	37	9	1-100 m	Vegetation, wastes [a, b]
180	25.89385000	49.57105000	Buqayq	Not found	Stagnant water	5	2	1-100 m	Vegetation, wastes [a, b]
181	25.89656667	49.57146667	Buqayq	Cx, Ae	Ditch	11	1.5	1-100 m	Vegetation, wastes [a, b]
182	25.89568333	49.57081667	Buqayq	Cx, Ae	Surface water	8	7	1-100 m	Vegetation, waste [a]
183	25.98181667	48.87166667	Buqayq	Cx, Ae, An	Surface water	31	11	1-100 m	Vegetation, waste [a]
184	25.97811667	48.86883333	Buqayq	Cx, Ae, An	Ditch	53	2	1-100 m	Vegetation, waste [a]
185	25.97171667	48.87161667	Buqayq	Cx, Ae, An	Surface water	35	13	1-100 m	Vegetation, waste [a]
186	26.42718333	50.02873333	Dammam	Not found	Ditch	45	1.5	1-100 m	Wastes [a, d]

187	26.42895000	50.02763333	Dammam	Not found	Sewage/surface water	40	20	1-100 m	Waste [a]
188	26.43128333	50.02658333	Dammam	Cx, Ae	Sewage water	60	50	1-100 m	Vegetation, wastes [a, b, d, e]
189	26.43181667	50.02510000	Dammam	Cx	Sewage/surface water	130	130	1-100 m	Wastes [a, b, d, e]
190	26.43263333	50.02571667	Dammam	Cx	Sewage/surface water	35	5	1-100 m	Vegetation, wastes [a, b,d, e]
191	26.43416667	50.02435000	Dammam	Not found	Sewage/surface water	30	15	1-100 m	Wastes [d, h]
192	26.43533333	50.02393333	Dammam	Cx	Sewage/surface water	60	15	1-100 m	Wastes [a, f]
193	26.43656667	50.02285000	Dammam	Cx, Ae	Sewage/surface water	35	6	1-100 m	Wastes [a, b, d]
194	26.43721667	50.02085000	Dammam	Not found	Sewage/surface water	35	32	1-100 m	Wastes [a, b, d, h]
195	26.43620000	50.02023333	Dammam	Not found	Sewage/surface water	12	4	1-100 m	Wastes [a, b, d]
196	26.43561667	50.01948333	Dammam	Not found	Sewage/surface water	10	5	1-100 m	Wastes [a, b, d]
197	26.43530000	50.01903333	Dammam	Not found	Sewage water	13	6	1-100 m	Wastes [a, b, d]
198	26.43521667	50.01851667	Dammam	Not found	Surface water	170	15	1-100 m	Wastes [a, b]
199	26.43180000	50.01270000	Dammam	Not found	Surface water	80	30	1-100 m	Wastes [a, b, d, f]
200	26.43280000	50.01411667	Dammam	Not found	Surface water	125	60	1-100 m	Wastes [a, b, d, f]
201	26.42118333	50.01675000	Dammam	Not found	Sewage/surface water	50	4	1-100 m	Wastes [a, b]
202	26.42466667	50.01865000	Dammam	Not found	Surface water	80	35	1-100 m	Wastes [a, b, c]
203	26.42288333	50.01890000	Dammam	Not found	Sewage/surface water	38	10	1-100 m	Wastes [a,b, f, h]
204	26.41760000	50.01528333	Dammam	Not found	Surface water	250	20	1-100 m	Wastes [a, b]

205	26.42471667	50.01141667	Dammam	Not found	Sewage/surface water	32	25	1-100 m	Wastes [a, b, d, i]
206	26.42750000	50.01063333	Dammam	Not found	Surface water	600	36	1-100 m	Wastes [a, b, d], salty
207	26.41533333	50.00728333	Dammam	Not found	Surface water	250	21	1-100 m	Wastes [a, b, d], salty
208	26.41955000	50.00393333	Dammam	Not found	Surface water	385	83	1-100 m	Wastes [a, b, d], salty
209	26.42620000	50.00423333	Dammam	Cx	Surface water	67	17	1-100 m	Vegetation, wastes [a, b]
210	26.42796667	50.00150000	Dammam	Not found	Surface water	655	22	1-100 m	Wastes [a, d, h], salty
211	26.42473333	50.00370000	Dammam	Not found	Surface water	88	18	1-100 m	Wastes [a, b, h]
212	26.42115000	50.00376667	Dammam	Not found	Surface water	55	21	1-100 m	Wastes [a, c]
213	26.41745000	50.00450000	Dammam	Not found	Surface water	91	23	1-100 m	Waste [a]
214	26.43123333	50.00671667	Dammam	Cx	Ditch	27	1.5	1-100 m	Waste [a]
215	26.40696667	50.01295000	Dammam	Cx, Ae	Surface water	123	45	1-100 m	Vegetation, waste [a]
216	26.40633333	50.01233333	Dammam	Not found	Surface water	73	22	1-100 m	Vegetation, wastes [a, b, d]
217	26.35586667	50.02608333	Dammam	Cx, Ae	Surface water	173	49	201-400 m	Vegetation, wastes [a, c]
218	26.41561667	50.16203333	Dammam	Not found	Sewage	11	4	1-100 m	Wastes [a, b, d, f]
219	26.41548333	50.16530000	Dammam	Not found	Sewage	11	3	1-100 m	Wastes [a, b, d]
220	26.41848333	50.16598333	Dammam	Cx	Sewage	9	4	1-100 m	Nothing
221	26.41716667	50.16576667	Dammam	Cx	Sewage	3	3	1-100 m	Wastes [a, b ,c]
222	26.41773333	50.16460000	Dammam	Not found	Sewage	12	5	1-100 m	Wastes [a, b, c, d]
223	26.41813333	50.16366667	Dammam	Cx	Sewage	33	7	1-100 m	Wastes [a, b, c, d]
224	26.52670000	50.00766667	UmmAlHamam	Cx	Ditch	80	0.5	1-100 m	Vegetation
225	26.51991667	49.98941667	UmmAlHamam	Cx, Ae, An	Stagnant water	30	3	1-100 m	Vegetation, wastes [a, b]
226	26.52825000	49.99188333	UmmAlHamam	Not found	Ditch	190	1	1-100 m	Wastes [a, b]
227	26.52746667	49.98955000	UmmAlHamam	Cx	Stagnant water	55	2	1-100 m	Wastes [a, b]
228	26.52680000	49.98836667	UmmAlHamam	Cx	Ditch	80	1	1-100 m	Vegetation
229	26.52696667	49.98753333	UmmAlHamam	Cx	Ditch	75	1	1-100 m	Vegetation, wastes [a, b]
230	26.52593333	49.98671667	UmmAlHamam	Cx, Ae, An	Stagnant water	50	3	1-100 m	Wastes [a, b]
231	26.52441667	49.98643333	UmmAlHamam	Cx, Ae, An	Stagnant water	5	0.5	1-100 m	Wastes [a, b]

232	26.52276667	49.98970000	UmmAlHamam	Not found	Stagnant water	65	2.5	1-100 m	Wastes [a, b]
233	26.51928333	49.98913333	UmmAlHamam	Cx, Ae	Ditch	125	1	1-100 m	Vegetation
234	26.52465000	49.98940000	UmmAlHamam	Not found	Ditch	95	1	1-100 m	Vegetation, wastes [a, b]
235	26.64883333	49.89921667	UmmuAs Sahik	Cx, Ae, An	Ditch/farm	400	1.5	101-200 m	Vegetation, wastes [a, b]
236	26.65258333	49.89386667	UmmAs Sahik	Cx	Stagnant water	459	3	101-200 m	Vegetation, wastes [a, b]
237	26.65335000	49.89690000	UmmAs Sahik	Cx, Ae	Ditch/farm	50	2	1-100 m	Vegetation, wastes [a, b, d]
238	26.65320000	49.88611667	UmmAs Sahik	Cx	Surface water	48	2	1-100 m	Vegetation
239	26.65341667	49.89923333	UmmAs Sahik	Cx, Ae, An	Ditch/farm	126	2	1-100 m	Vegetation, wastes [a, b]
240	26.65441667	49.89925000	UmmAs Sahik	Cx, Ae, An	Ditch	1.5	1	1-100 m	Wastes [a, b]
241	26.66118333	49.89256667	UmmAs Sahik	Not found	Stagnant water	18	5	1-100 m	Wastes [a, b]
242	26.66336667	49.88523333	UmmAs Sahik	Culex	Farm	2	1.5	1-100 m	Vegetation, wastes [a, b]
243	26.66288333	49.88375000	UmmAs Sahik	Cx, An	Farm	2	1.5	1-100 m	Vegetation, wastes [a, b], algae
244	26.65811667	49.91503333	UmmAs Sahik	Cx, Ae, An	Ditch/farm	45	1.5	201-400 m	Vegetation, wastes [a, b, d]
245	26.65775000	49.91360000	UmmAs Sahik	Cx, Ae, An	Ditch/farm	87	1.5	201-400 m	Vegetation, waste [a], algae
246	26.65876667	49.91395000	UmmAs Sahik	Cx, Ae, An	Farm	287	1	201-400 m	Vegetation, waste [a], algae
247	26.65760000	49.91290000	UmmAs Sahik	Cx, Ae	Ditch/farm	119	2	101-200 m	Vegetation, waste [a]
248	26.65841667	49.91173333	UmmAs Sahik	Cx, Ae	Stagnant water	18	2	201-400 m	Vegetation, waste [a]
249	26.65826667	49.91083333	UmmAs Sahik	Not found	Ground water	2	1.5	201-400 m	Nothing
250	26.64516667	49.91253333	UmmAs Sahik	Cx, An	Ditch/Farm	17	2	1-100 m	Vegetation, wastes [a, b, f]
251	26.64478333	49.91296667	UmmAs Sahik	Cx	Surface water	9	2.5	1-100 m	Vegetation
252	26.64520000	49.91288333	UmmAs Sahik	Cx, Ae	Ditch/Farm	3	1	1-100 m	Vegetation, wastes [a, b, h]
253	26.64593333	49.90583333	UmmAs Sahik	Cx	Ditch/Farm	12	0.5	201-400 m	Vegetation
254	26.64566667	49.90385000	UmmAs Sahik	Cx, An	Ditch/Farm	89	1	201-400 m	Vegetation, wastes [a, b]
255	26.63723333	49.92450000	UmmAs Sahik	Cx, Ae, An	Ditch/Farm	96	1	101-200 m	Vegetation, algae
256	26.52868333	50.01856667	Anak	Cx	Ditch/Farm	32	1	1-100 m	Vegetation, waste [a]

257	26.52915000	50.01960000	Anak	Cx	Ditch/Farm	87	1.5	1-100 m	Vegetation, wastes [a, b]
258	26.53013333	50.02183333	Anak	Cx	Ditch/Farm	105	2	1-100 m	Vegetation, wastes [a, b]
259	26.53003333	50.01670000	Anak	Not found	Ditch/Farm	268	2.5	1-100 m	Vegetation, waste [a], algae
260	26.54378333	49.98516667	KhuwaIldiyah	Cx	Ditch	30	1.5	1-100 m	Vegetation, wastes [a, b]
261	26.54710000	49.97726667	Khuwaildiyah	Cx, Ae, An	Ditch/Farm	26	1.5	1-100 m	Vegetation, waste [a]
262	26.55321667	49.98213333	Khuwaildiyah	Cx, Ae, An	Ditch	50	2	1-100 m	Vegetation, waste [a]
263	26.55175000	49.97865000	Khuwaildiyah	Cx	Ditch	100	1.5	1-100 m	Vegetation, waste [a], algae
264	26.55161667	49.98073333	Khuwaildiyah	Not found	Ditch	15	0.5	1-100 m	Vegetation, waste [a], algae
265	26.54876667	49.98691667	Khuwaildiyah	Not found	Stagnant water	11	2	1-100 m	Vegetation, wastes [a, b]
266	26.54651667	49.99376667	Khuwaildiyah	Cx	Stagnant water	5	2	1-100 m	Vegetation, wastes [a, b]
267	26.54501667	49.99356667	Khuwaildiyah	Not found	Farm	8	2	201-400 m	Vegetation, wastes [a, b]
268	26.55710000	49.98675000	Tawbi	Not found	Stagnant water	20	3	1-100 m	Vegetation
269	26.55641667	49.98505000	Tawbi	Cx, Ae, An	Farm	13	1.5	1-100 m	Vegetation
270	26.55490000	49.98721667	Tawbi	Cx, Ae, An	Farm	10	1	1-100 m	Vegetation
271	26.55496667	49.98805000	Tawbi	Cx, Ae, An	Farm	70	1	1-100 m	Vegetation
272	26.53820000	50.01060000	Al Qatif	Cx, An	Ditch/farm	135	2	1-100 m	Vegetation, wastes [a, b]
273	26.53910000	50.01191667	Al Qatif	Cx, Ae, An	Ditch/farm	129	2	1-100 m	Vegetation, wastes [a, b]
274	26.54000000	50.01471667	Al Qatif	Not found	Ditch/farm	129	2	1-100 m	Vegetation, waste [a]
275	26.54090000	50.01553333	Al Qatif	Cx, Ae	Ditch	376	3	1-100 m	Vegetation, waste [a]
276	26.54411667	50.01326667	AlnQatif	Cx, Ae	Ditch	374	2	1-100 m	Vegetation, wastes [a, b]
277	26.53663333	50.01160000	Al Qatif	Not found	Farm	45	3	1-100 m	Vegetation
278	26.53786667	50.01666667	Al Qatif	Not found	Ditch/farm	163	2	1-100 m	Vegetation, wastes [a, b]
279	26.53601667	50.01766667	Al Qatif	Cx, Ae, An	Ditch/farm	68	5	1-100 m	Vegetation, waste [a], algae

280	26.53618333	50.01855000	Al Qatif	Cx, Ae	Ditch/farm	53	4	1-100 m	Vegetation, waste [a], algae
281	26.65946667	49.96558333	Safwa	Not found	Ditch/Farm	50	1.5	1-100 m	Vegetation, waste [a]
282	26.65998333	49.96546667	Safwa	Cx, Ae, An	Ditch/Farm	10	2	1-100 m	Vegetation, waste [b]
283	26.66113333	49.96730000	Safwa	Cx. Ae, An	Ditch/Farm	89	1	1-100 m	Vegetation, wastes [a, b]
284	26.66063333	49.96491667	Safwa	Ae, An	Ditch/Farm	27	2	1-100 m	Vegetation, waste [a]
285	26.66488333	49.96421667	Safwa	Cx, Ae	Ditch/farm	29	2	1-100 m	Vegetation, waste [f]
286	26.66431667	49.96401667	Safwa	Not found	Ditch/farm	31	2	1-100 m	Nothing
287	26.66341667	49.96736667	Safwa	Not found	Ditch/farm	15	2	1-100 m	Vegetation, wastes [a, b]
288	26.66375000	49.96843333	Safwa	Not found	Ditch/farm	135	2	1-100 m	Vegetation, wastes [a,b,d,g]
289	26.66403333	49.96981667	Safwa	Not found	Ditch/farm	156	2.5	101-200 m	Vegetation, wastes [a,b,d,g]
290	26.66465000	49.97118333	Safwa	Not found	Ditch/farm	98	3	1-100 m	Vegetation, wastes [a, b]
291	26.66478333	49.97298333	Safwa	Not found	Ditch/farm	350	2	201-400 m	Vegetation, wastes [a, b]
292	26.66208333	49.97366667	Safwa	Not found	Ditch/farm	350	2	1-100 m	Vegetation, wastes [a, b]
293	26.66126667	49.97641667	Safwa	Not found	Sewage/farm	10	2.5	1-100 m	Vegetation, wastes [a, b]
294	26.66786667	49.97301667	Safwa	Cx, Ae	Ditch/Farm	94	2	401-800 m	Vegetation, wastes [a, b]
295	26.66933333	49.97295000	Safwa	Not found	Ditch	40	3	401-800 m	Vegetation
296	26.66421667	49.96868333	Safwa	Cx, Ae, An	Ditch/farm	200	2	1-100 m	Vegetation, wastes [a, b, d]
297	26.66606667	49.96708333	Safwa	Cx, Ae	Ditch	5	1	1-100 m	Vegetation, wastes [a, b, d]
298	26.66900000	49.96575000	Safwa	Cx, Ae	Ditch/farm	265	2	1-100 m	Vegetation, wastes [a, b]
299	26.66803333	49.96330000	Safwa	Cx, Ae, An	Ditch/farm	20	3	1-100 m	Vegetation, wastes [a, b]
300	26.66896667	49.96446667	Safwa	Cx, Ae, An	Ditch/farm	200	3	1-100 m	Vegetation, wastes [a, b]
301	26.49436667	50.02556667	Saihat	Not found	Ditch	150	1.5	1-100 m	Vegetation, small fish
302	26.49558333	50.02181667	Saihat	Cx	Ditch	100	2	1-100 m	Vegetation, wastes [a, b]
303	26.49345000	50.02281667	Saihat	Cx, An	Farm	3	1	1-100 m	Vegetation, wastes [a,b,d,g]
304	26.49088333	50.02276667	Saihat	Cx, An	Ditch	800	1.5	101-200 m	Vegetation, wastes [a,b,d,g]

305	26.49216667	50.02865000	Saihat	Not found	Surface water	30	7	1-100 m	Vegetation, wastes [a, b]
306	26.49586667	50.02688333	Saihat	Cx	Ditch	145	1.5	1-100 m	Vegetation, wastes [a, b]
307	26.49696667	50.02651667	Saihat	Not found	Stagnant water	40	2.5	1-100 m	Vegetation, wastes [a, b]
308	26.49595000	50.02475000	Saihat	Not found	Stagnant water	65	2.2	1-100 m	Vegetation, wastes [a, b]
309	26.55825000	50.08088333	Tarout	Cx, An	Stagnant water	10	2.5	1-100 m	Vegetation, wastes [a, b]
310	26.55740000	50.08038333	Tarout	Not found	Stagnant water	35	3	101-200 m	Vegetation
311	26.55773333	50.08001667	Tarout	Cx	Stagnant water	13	2	101-200 m	Vegetation, wastes [a, b, d]
312	26.55606667	50.07961667	Tarout	Cx, Ae	Ditch	10	2.5	1-100 m	Vegetation, wastes [a, b, d]
313	26.56456667	50.06295000	Tarout	Cx, Ae	Stagnant water	5	2	1-100 m	Vegetation, wastes [a, b]
314	26.56070000	50.06143333	Tarout	Cx	Ditch	30	2.5	1-100 m	Vegetation, wastes [a, b]
315	26.58753333	50.05480000	Tarout	Not found	Ditch	130	2	1-100 m	Vegetation, wastes [a, b]
316	26.58915000	50.05668333	Tarout	Cx, Ae	Ditch	115	3	1-100 m	Vegetation, wastes [a, b, d]
317	26.58333333	50.05875000	Tarout	Cx, Ae, An	Ditch	50	2	1-100 m	Vegetation, wastes [a, b, d]
318	26.58040000	50.05565000	Tarout	Not found	Ditch	60	2	1-100 m	Vegetation, wastes [a, b]
319	26.58755000	50.05370000	Tarout	Not found	Stagnant water	5	2	1-100 m	Vegetation, wastes [a, b]
320	26.58761667	50.06518333	Tarout	Cx, An	Ditch	125	2.5	1-100 m	Vegetation, wastes [a, b]
321	26.56913333	50.08691667	Tarout	Cx, Ae	Stagnant water	3	3	1-100 m	Vegetation, wastes [a, b]
322	26.58918333	50.06715000	Tarout	Cx, An	Ditch	100	2.5	101-200 m	Vegetation, wastes [a, b]

Cx = Culex, Ae = Aedes, An = Anopheles

L = length of the water body, W= Width of the water body, m= meter

a= plastic, b= paper, c= cloth, d= old tires, e= bottles, f= woods, g= old housing furnitures, h= iron/cans, i= glass

VITAE

1. Personal Information:

Name : Yasin Jemal Yasin

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2. Educational background:

University	Date of graduation	Degree obtained
King Fahd University of Petroleum and Minerals	October 2015	MSc in Environmental Science
Addis Ababa University	July 2010	Master of Public Health (MPH)
Haramaya University	July 2006	BSc in Environmental Health

3. Certificate:

University	Date obtained	Certificate obtained
Wolaita Sodo University	July 2011	Higher Diploma License as a Certified Professional Teacher

4. Awards and scholarships

Year	Award or scholarship
2008 -2010	Full time scholarship by Wolaita Sodo University, Ministry of Education, Ethiopia
2013- 2015	Full time scholarship by King Fahd University of Petroleum and Minerals, Ministry of Higher Education, Saudi Arabia

5. Teaching

Department/school	University	Period of service	Position
School of Public Health	Wolaita Sodo University	Jul 24, 2010 – Oct 30, 2013	Lecturer
Environmental Health Department	Wolaita Sodo University	Feb 01, 2008-Jul 23, 2011	Graduate assistant II and department head
Environmental Health Department	Wolaita Sodo University	Feb 01, 2007- Jan 31, 2008	Graduate assistant I and department head

6. Courses taught:

- Health service management
- Health economics
- Health education and promotion
- Epidemiology
- Introduction to environmental health
- Human ecology
- Water supply I and II

7. Computers skills:

- MS word, excel, power point
- Program software: GIS, SPSS, Epi-Info